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Technical Report No. 32-444

SYNCOM I Igniter Squib Development and Qualification

M. Joseph Cork

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M. Joseph Cork

L. Piasecki

L. Piasecki, Chief
Solid Propellant Engineering Section

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II

FIGURES

FOREWORD

As this Report was being published, another change in the Cannon connector configuration of the squib-cable assembly was in process. Therefore the configuration shown in this Report is not final. However, since the purpose of this Report is to describe the squib development and qualification program, the original configuration was retained as being representative of a typical configuration. The final cable configuration will be shown in the SYNCOM I Project Report.

ABSTRACT

The SYNCOM I igniter squib was manufactured by Special Devices, Incorporated, of Newhall, California, to JPL specifications. The squib is a dual-bridge wire unit with either wire capable of igniting the main charge. It has met the Atlantic Missile Range requirement that a squib shall not fire when: (a) subjected to one amp of current per firing circuit for five minutes and (b) required to dissipate one watt of power per firing circuit for five minutes. The squib has also successfully passed an environmental qualification test program at JPL which included squib firings to verify consistent operation and motor tests to show reliable ignition. This Report describes the squib design, development history, and qualification program; the general aspects of these areas are presented in the body of the Report, and the more specific design and test details are discussed in four Appendixes.

I. INTRODUCTION

The Goddard Space Flight Center formally undertook Project SYNCOM I in August 1961. The objective is to provide narrowband communications with a light-weight Earth satellite in a 24-hr orbit. A three-stage Thor-Delta vehicle will boost the spacecraft into an elliptical transfer orbit with the apogee at synchronous altitude. A solid-propellant rocket motor in the satellite will be fired at apogee to give the satellite near-synchronous velocity.

Hughes Aircraft Company was selected as the prime contractor for this program, and the Elkton Division of Thiokol Chemical Company was chosen to provide the apogee kick motor, a modification of the Thiokol TE-345 motor. Concurrently the Jet Propulsion Laboratory contracted to develop a high performance motor optimized for the SYNCOM I mission. This Report describes the development chronology, design, and qualification of the igniter squib for the JPL SYNCOM I motor shown in Fig. 1.

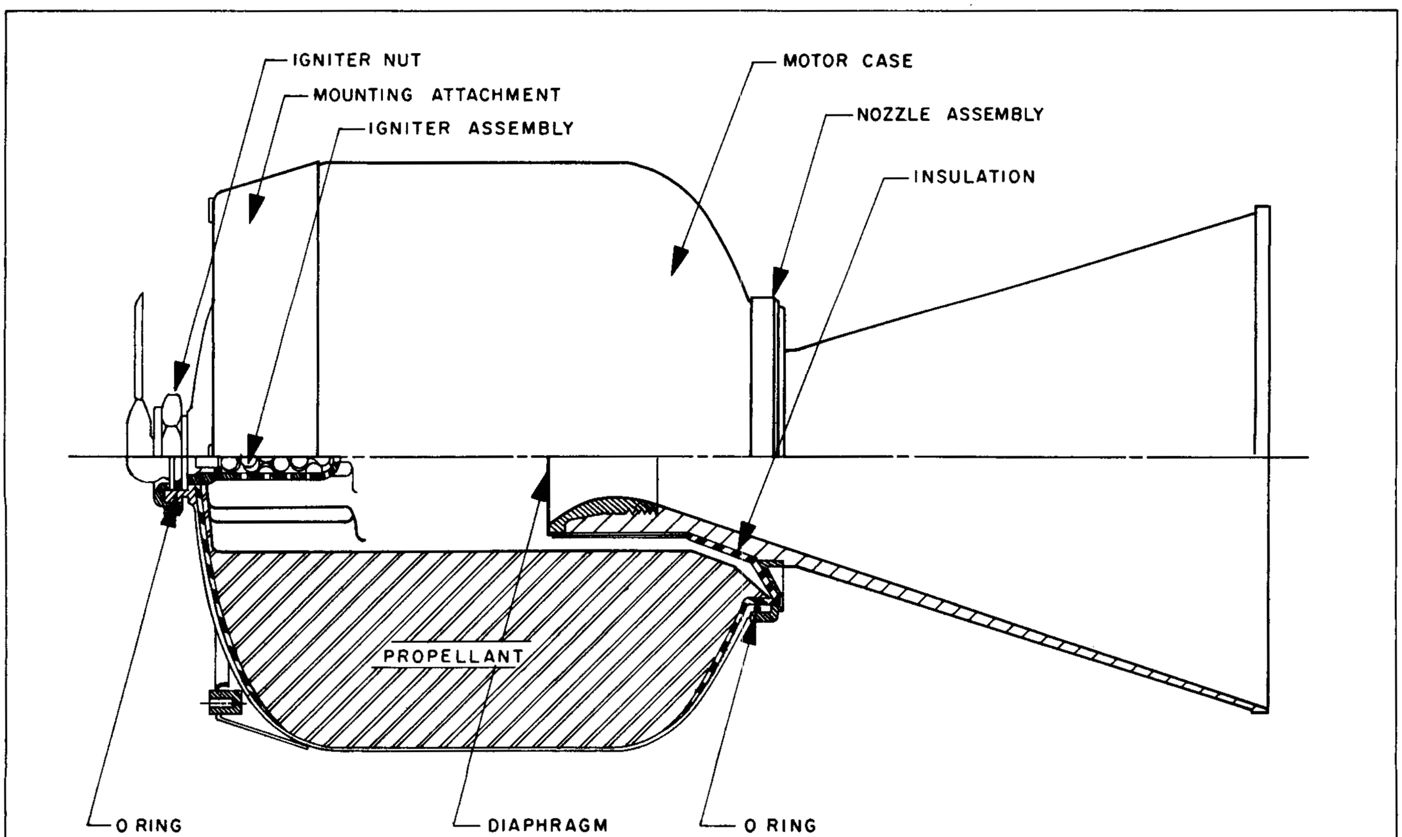


Fig. 1. SYNCOM I motor assembly

II. SQUIB DESIGN AND DEVELOPMENT

A. Chronological Development

At the inception of the SYNCOM I program a decision was made to use an igniter squib developed especially for the program. This decision was brought about primarily by the new Atlantic Missile Range requirement that no more than one squib in a thousand could fire with: (a) the application of one ampere of current for five minutes and (b) the dissipation of one watt of power for five minutes. The squib geometry was affected by the desire to use only one O-ring seal in the motor head end; the resultant specification called for a flange on the squib body large enough to cover the igniter diameter. Special Devices, Incorporated (SDI), of Newhall, California, contracted to design and develop a unit to the above specifications and others listed in Table 1.

Table 1. Squib design specifications

The SYNCOM ignition squib shall meet the following minimum requirements.

1. The squib shall contain four pins with dual bridge wires.
2. The squib body shall conform to a Bendix Pigmy PTOOP-8-4P receptacle.
3. The squib body shall conform to the external dimension given in JPL blueprint C 390 1319-1.
4. The squib shall conform to the following electrical specification:
   1 amp, 1 w for 5 min: no fire
   4.5 amp, 0.020 sec: all fire
   (test temp., 70-80° F)
5. The squib shall ignite AGC 0-052 Alclo pellets. This test will be conducted with the pellets placed a minimum distance of 0.125 inches from the face of the squib. Test temperature 70 to 80° F. This test shall be conducted in vacuum.
6. The squib shall be designed to be operable after being subjected to vibration. The expected vibration conditions that the squib may experience are given in Appendix B.
7. The squib shall be operable over the temperature range of 10 to 140° F.
8. The squib shall be operable after being subjected to a vacuum of 10^{-5} mm Hg for a period of 5 hr. The metal squib closure shall be broken during vacuum exposure.

A few prototypes were manufactured with an energy output of 160 calories, but the charge requirement was increased to 400 calories because of the substitution of Alclo for boron igniter pellets to give more positive motor ignition (the original design specification called for USF-2D boron pellets). Eleven squibs were then delivered with a 490-milligram pellet charge ignited by 30 mg of primer. When some of these squibs were fired into aspirin-filled igniter baskets, however, they pulverized the aspirin tablets and broke the baskets. It was determined that the primer was burning too fast and creating a shock wave, so a slower burning primer was substituted. This primer, however, failed to ignite the main squib charge in two 10°F tests. At this time the squib design was re-evaluated, and a powdered charge formulation using beaded bridgewires for ignition was decided upon. This design proved satisfactory in preliminary tests and was approved for the squib qualification program.

Meanwhile the restrictions on available space at the head end of the motor were being tightened by Hughes Aircraft Company. The squib was moved into the motor as far as was practical, but there was not enough room for the designated Bendix connector. A permanent pigtail connector was designed for the flight squibs which fits within the given envelope and places the electrical interface in the same location for either the JPL or Thiokol motor.

A total of 245 squibs were purchased from SDI for the SYNCOM I Program. Seventy of the design discussed herein were for squib qualification and flight, while an additional 175 units with two pressure taps attached to the squib flange were purchased for use in motor and igniter tests.

B. Design Details

Figure 2 shows the SYNCOM I squib design, Fig. 3 illustrates the squib-cable assembly design, and squib and assembly configurations are shown in Fig. 4. Table 2 presents the more important characteristics of the squib, while material specifications and manufacturing techniques are given in Appendix A.

The dissipation of 1 w in each circuit for 5 min, required by the Atlantic Missile Range, is made possible by placing a bridgewire across an insulator on each pin, as shown in Fig. 2. This pin bridgewire is surrounded by a potting compound which acts as a heat sink. Beaded bridgewires are then placed across the ends of pins A-D and B-C to form two parallel circuits of 3 resistors each.

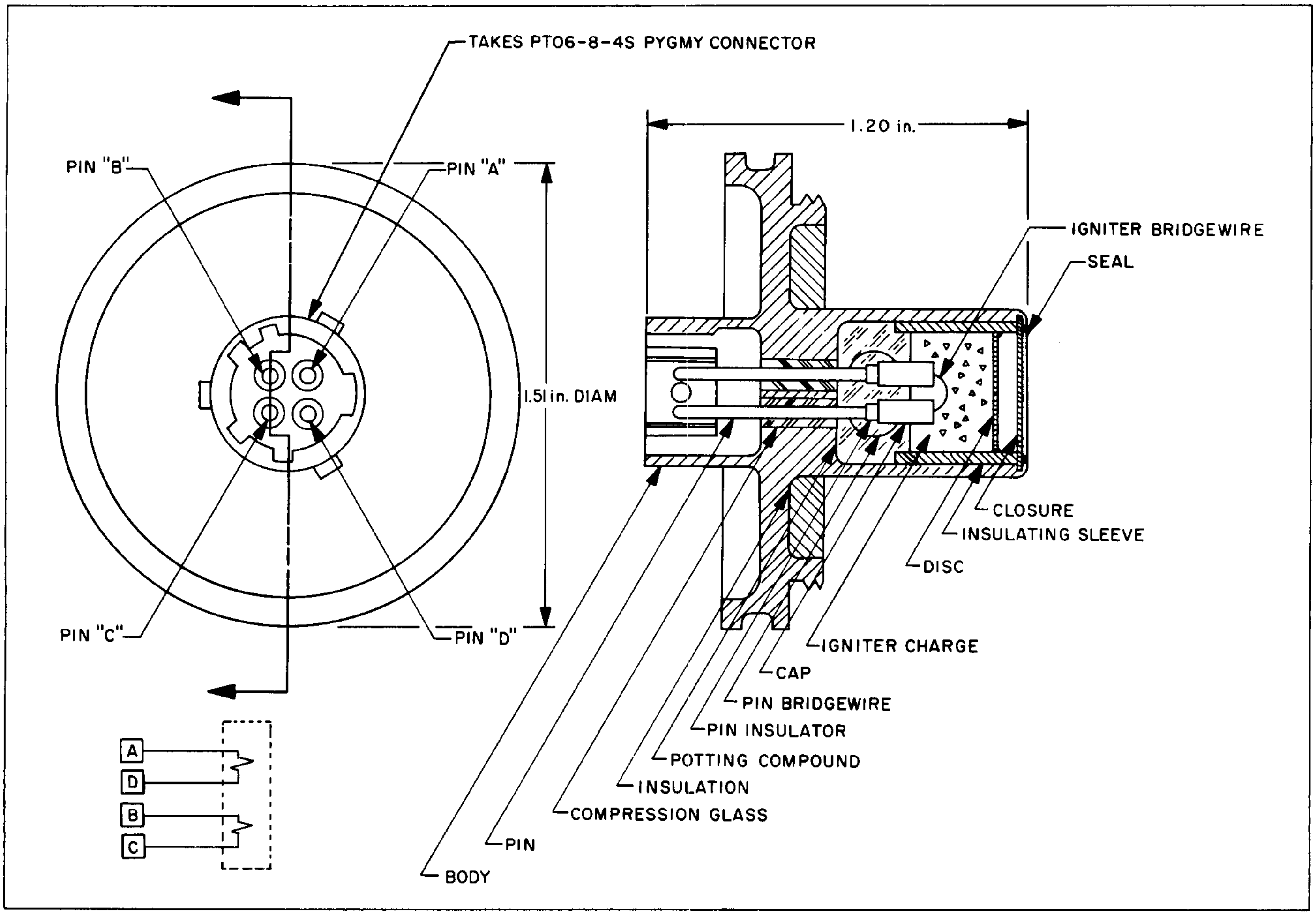


Fig. 2. SYNCOM I igniter squib

The resistances are controlled so that, if a circuit dissipates 1 w, no more than 0.4 w is dissipated across the beaded bridgewire.

The pigtail connectors used on the flight squibs are manufactured by JUTCO, Inc., of Gardena. The potting of the right angle bend is accomplished with a cavity mold, while a standard potting boot is used at the Cannon connector end. Hughes mounting specifications, which call for the Cannon connector to go through a relatively small hole in the spacecraft structure, are responsible for the unorthodox method of attaching the connector.

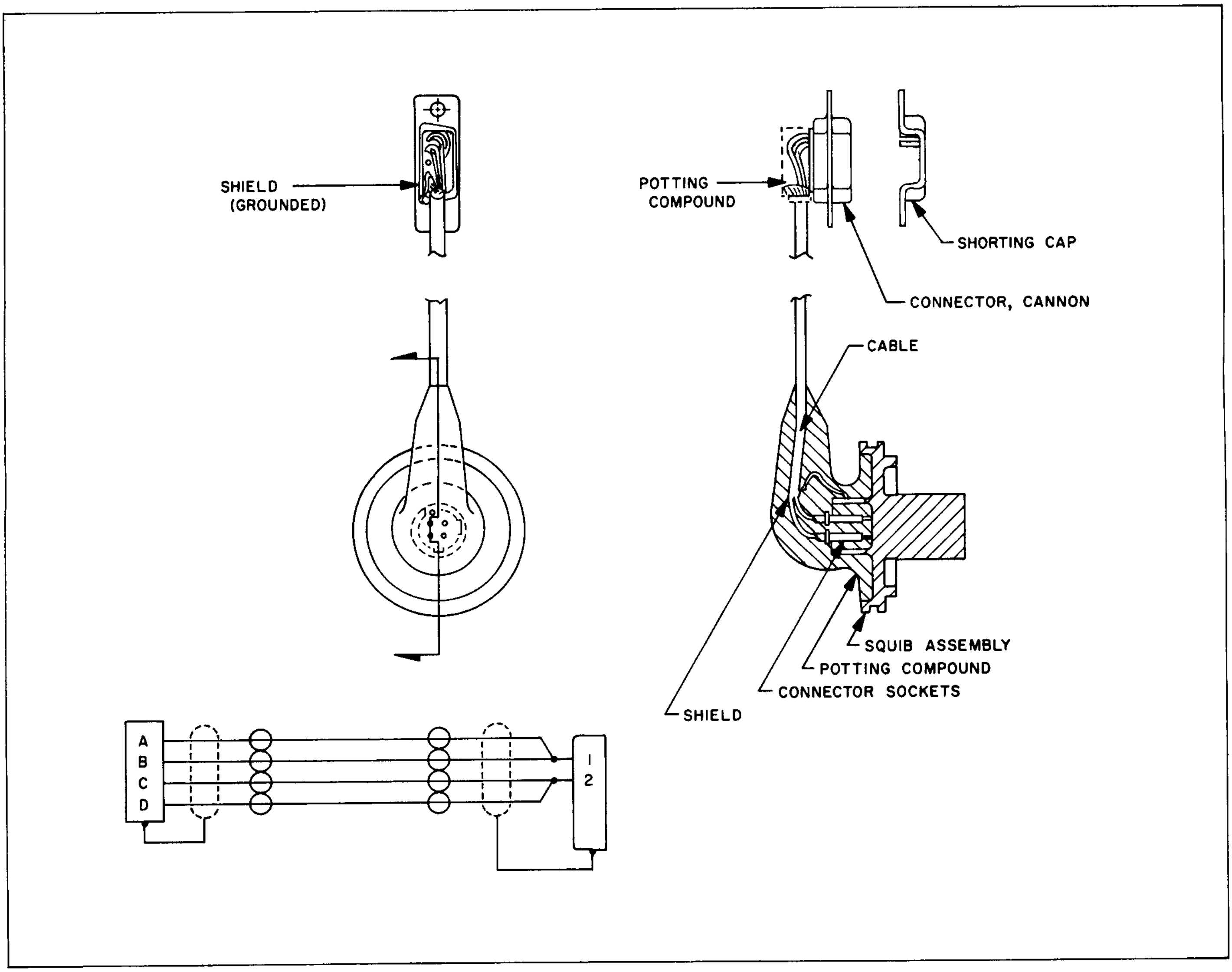


Fig. 3. SYNCOM I squib-cable assembly

Table 2. Squib characteristics

1. General description: four pin, dual-firing circuit squib with permanently attached connector
2. Manufacturer:
   a. Squib: Special Devices, Incorporated, Newhall, California
   b. Connector: JUTCO, Incorporated, Gardena, California
3. Typical circuit resistances:
   a. Squib: 1 to 1.3 ohms per circuit
   b. Squib connector: 0.55 to 0.65 ohms (two squib circuits in parallel).
4. Firing currents:
   a. Nominal firing current: 4.5 amps per squib circuit
   b. No-fire current (99.9% reliable, 95% confidence level): 1.25 amps per squib circuit
   c. All-fire current (99.9% reliable, 95% confidence level): 2.47 amps per squib circuit
5. Operational characteristics:
   a. Squib delay time at 4.5 amps per circuit: 15 to 20 msec.
   b. Nominal energy output: 400 cal from 400 mg of powdered charge
   c. Flame temperature: 3300° F
6. Nominal weights:
   a. Squib: 47 g
   b. Squib with connector: 78 g

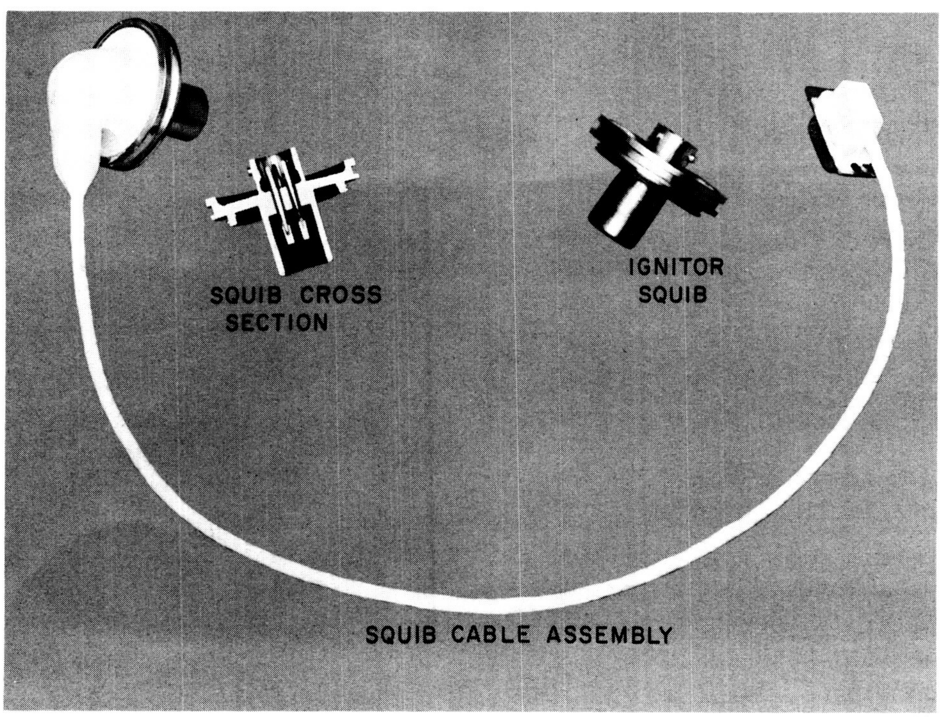


Fig. 4. Squib configurations

III. SQUIB QUALIFICATION PROGRAM

A test program was carried out by JPL and SDI to qualify the SYNCOM I squib for flight. Following are summaries of the objectives, test procedures, and results of the three phases of this program. More detailed reports including equipment and procedures used, test data, and specific test results of the tests (described in A and B, below) are presented in Appendixes B and C, respectively. The details of the igniter and full scale motor firings (described under C, below) are reported in other documents. The three phases were carried out simultaneously after preliminary development tests had indicated successful results in each area.

A. *Environmental and Operational Tests*

1. Objectives

To evaluate the effects of temperature shock, vibration, and vacuum exposure tests on the squib; to evaluate the operating characteristics of the squib in vacuum and at ambient pressure over a range of temperatures; to evaluate the effect of AMR no-fire tests on squib operating characteristics.

2. Test Procedures and Results

Thirty-six squibs were subjected to the test program outlined in Fig. 5. All squibs were subjected to temperature shock tests of 1 hr at −65°F, 1 hr at 165°F, and 1 hr at −65°F. They were then vibrated according to the specification outlined in Table B-3. The squibs were separated and fired into closed test chambers at varying temperatures and pressures as shown in Fig. 5. Prior to firing, however, a vacuum exposure test of 5 hr duration at ambient temperature was given one group of squibs with punctured seals, and an AMR no-fire test of 2 amps applied in parallel for 5 min was given to another group. Examination of the resistance data taken after each test phase and the pressure and current-time data from the firings yielded the following conclusions:

1. The squib is not susceptible to vibration or temperature-shock damage.
2. Squib delay time (current initiation to peak pressure of 15-20 msec) and squib energy output are not affected significantly by temperature or pressure variations within the ranges investigated.
3. The vacuum exposure of the squib charge and AMR no-fire tests have no significant effects on squib firing characteristics.

B. *All-Fire–No-Fire Reliability Tests*

1. Objective

To evaluate the all-fire–no-fire characteristics of the SYNCOM I squib.

2. Test Procedures and Results

SDI carried out a Bruceton analysis with 21 squibs to evaluate the all-fire and no-fire current levels. Before the Bruceton tests the squibs were subjected to temperature shock, jolt, and vibration tests as described in Appendix C. The Bruceton results show a 99.9% reliable, 95% confidence level, maximum no-fire current of 1.25 amps per circuit. This corresponds to a power dissipation of 1.5 to 2 w per circuit for 5 min, and it is well above the AMR 1 amp-1 w requirement. The tests also show an all-fire current with the same reliability and confidence level of 2.47 amps per circuit, well below the nominal firing current of 4.5 amps.

C. *Igniter and Motor Tests*

1. Objective

To evaluate the squib's effectiveness in igniting Alclo pellets over a range of temperatures in vacuum and at ambient pressure.

2. Test Procedures and Results

The ignition problems encountered during the development phase were discussed previously. Since the final squib design was frozen, production squibs have successfully initiated 126 igniter tests, ignition test motors, and full scale motors of the SYNCOM I igniter and motor qualification programs without a failure in the squib-igniter ignition link. These tests were made at vacuum and ambient pressure over a temperature range of 10°F to 140°F, and the results indicate a suitable level of ignition reliability. Post-fire short tests were made on 111 of these squibs with no shorts recorded, thus tending to allay fears of a post-fire short draining electrical power.

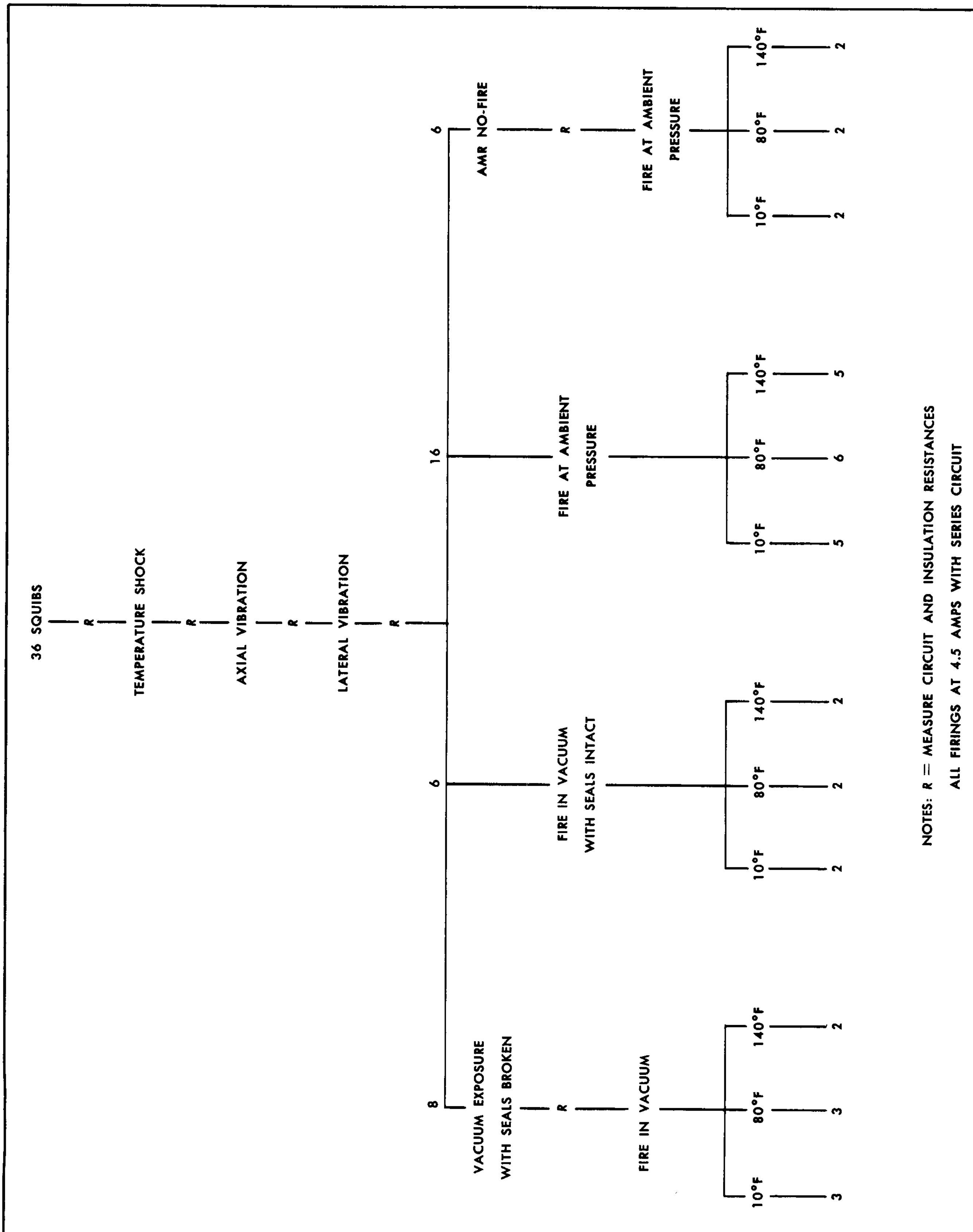


Fig 5. Environmental and operational tests

IV. SQUIB FLIGHT ACCEPTANCE PROGRAM

The flight acceptance testing carried out on the SYNCOM I squibs consisted largely of more detailed inspection than was used on the test items. The squib resistances were checked against SDI records on receipt, and the cables were then manufactured by JUTCO. Total assembly resistance checks, 500v shorted-pin-to-body dielectric readings, and shield continuity tests were made on the flight assemblies. Each squib was then X-rayed to verify bridgewire beading and charge loading compactness. Five squibs were selected for flight on the basis of the inspection data.

Four of the squib assemblies were subjected to temperature shock and vibration tests and were fired to obtain batch-check performance data. Neither the cable nor the squib of any assembly was damaged during the tests, and the squib firing characteristics were within the range established in the qualification tests.

Further details of the flight acceptance testing and the individual data are presented in Appendix D.

APPENDIX A

Squib Design

I. DESIGN AND MANUFACTURING DATA

Tables A-1 and A-2 present the design and manufacturing details of the squib and squib-cable assembly, respectively. The procedures are not meant to be a complete SOP as SDI and JUTCO each have their own procedural specifications. An attempt was made, however, to describe completely the technical details of each item.

The specifications listed for internal pressure and dielectric testing of the squib are quite conservative. It is estimated that the glass seal configuration would withstand at least 30,000 psi without failing—three times the acceptance test level. Also, the minimum dielectric strength of the flight assemblies was 500 megohms at 500 VDC as opposed to the acceptance level of 2 megohms.

II. VACUUM AND TEMPERATURE CHARACTERISTICS

Cannon connectors with diothiolate inserts, teflon-wrapped cable, and a silica-filled potting epoxy were chosen for the squib-cable assembly on the basis of their lack of decomposition under vacuum exposure. Also the copper-tin plating technique used on the squib body is second only to gold plating in off-gassing characteristics among metals. The Poly-Ep used for the squib seal and the polyester resin used internally in the squib do not have the best vacuum durability, but their positions with respect to satellite instruments are not critical.

SYNCOM squibs have been successfully operated at temperatures of 140°F and have been exposed to 165°F in temperature shock tests with no apparent damage. Following are critical temperature levels as estimated by the manufacturer.

200–250°F	Poly-Ep seal begins to outgas at about 210°F and flake between 210 and 250°F. Integrity of seal is not guaranteed above 200°F.
250–300°F	Polyester resin potting compound used within squib body begins to char above 250°F.
500–700°F	Auto ignition temperature.

III. EXPLOSIVE CHARACTERISTICS

The SYNCOM I squib is a Class C explosive which produces a hot flame but a small amount of gaseous products. It is insensitive to shock and will withstand a 40-ft drop onto a steel plate without detonation. In atmospheric conditions the squib produces a flame plume about 14 in. long with a maximum diameter of about 3 in. The metal closure could be dangerous to a bystander's eyes if a squib were ignited in the open.

Table A-1. Squib design and manufacturing details

Manufacturing step	Materials	Procedure	Specifications	Vendor
Manufacture body	AISI B 1113 STL (medium steel)	Machine from block	SDI Drawing No. 1J35-5.11	Device Seals, Inc., North Hollywood
Fabricate and assemble pin-contact assembly	Pin-contact: #52 alloy ¾ H Insulator tube: aluminum oxide Cap: #52 alloy ¾ H Bridgewire: nichrome type Cement: Astroceram Type A	Cement pin, tube, and cap together Resistance-weld bridgewire in place Coat bridgewires with cement	Before bridging, gap to read 1 megohm at 500 VDC SDI 1J35-5.17, 5.18, 5.19, 5.20	Cap Machining: Device Seals, Inc. Assembly: Special Devices, Inc.
Mate body and pin-contact assembly to form body subassembly	Pressure seal: high temperature compression glass, low lead content	Melt glass beads to form seal at 1750° F	Dielectric strength of glass to metal seal: 2 megohm minimum at 500 VDC Internal pressure test: 10,000 psi, 10 sec duration SDI 1J35-5.8	Device Seals, Inc.
Plate body subassembly	Copper, tin plate	Plate body subassembly with charge cavity masked off	Copper plate: 0.0004-0.0006 thick per Mil-C-14550 Tin plate: 0.0001-0.0002 thick per Mil-T-10727, Type I, hot oil fused SDI 1J35-5.8	Pacific Plating Co., Los Angeles
Insulate body	Sleeve: glass filled melamine Cement: Cycleweld LAC-14, catalyst C-14B Potting Compound: polyester resin	Cement sleeve in place Pot bottom of cavity, enclosing pin bridgewires	SDI 1J35-5.6, 5.16	Special Devices, Inc.
Bridge circuits	Bridgewire: nichrome type	Resistance-weld bridgewire in place	Total resistance each circuit: 1.00-1.40 ohms SDI 1J35-5.2	Special Devices, Inc.
Load and seal squib	Bridge beading (primer): zirconium, ammonium perchlorate, polyisobutylene Main charge: cupric oxide, aluminum, potassium perchlorate, boron, polyisobutylene Disc: mica Cement for disc: Cycleweld LAC-14, catalyst C-14B Closure: 0.010-in-thick lead Seal: Poly-Ep, Thermech Eng. Co.	Bead bridgewires Load 395-405 mg of main charge Cement disc in place Install closure and crimp body Seal closure	Shorted pins to body to read 2 megohms minimum at 500 VDC for 30 seconds SDI 1J35-5.1, 5.32	Special Devices, Inc.

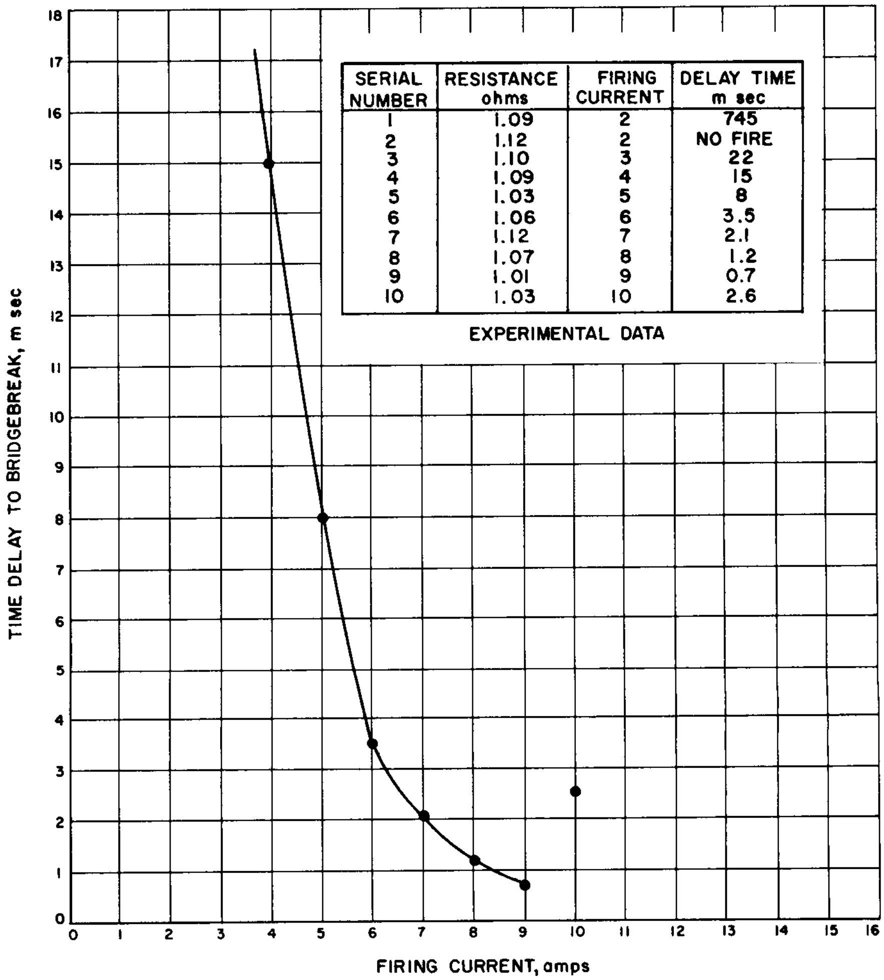
Table A-2. Squib-cable assembly design and manufacturing details

Manufacturing step	Materials	Procedure	Specifications	Vendor
Shorting plug	Plate: 0.010 copper-beryllium Pins: DSM connectors	Cut plate and form Cut holes in plate and solder pins in place Paint top red	JPL Drawing No. B-3901339	JUTCO, INC., Gardena
Material preparation	Connectors: Cannon DEM-9P-NM-10 Cable: HITEMP 4MW24-732STJB	Pigeonhole conductors through shield at each end of cable length; prepare ends Cut off connector solder pots 3, 6, 7, 8, 9, and file smooth		JUTCO
Cable-connector assembly		Solder bus wire from pin 4 to connector shell Solder shield between pins 4 and 5 Solder conductors to pins 1 and 2, as shown on Fig. 3, and dress	JPL Drawing C-3901333A with shield grounding changes authorized in purchase order Fig. 3 shows actual configuration	JUTCO
Squib-cable assembly[a]	Connector socket: Amphenol 17-764-02-50	Insert shield through hole on squib body and solder Sweat solder connector sockets to squib pins Solder conductors to connector solder pots as shown on Fig. 3	Same as previous step	JUTCO
Potting[a]	HYSOL 4187 epoxy with 3404 hardener; 12-hr cure time at room temperature EPD 2575 epoxy used as primer	Clean parts with a solvent Pot squib connection in cavity mold Pot connector in cannon potting boot; remove boot, and grind molding to required height	Same as previous step Shorted pins to body to read 2 megohms minimum at 500 VDC	JUTCO

[a]The order in which the last two steps are done may be varied to suit the manufacturer. The squibs were molded two at a time. For handling ease the potting of both ends of an item at the same time was not attempted.

IV. IGNITION CHARACTERISTICS

SDI carried out a series of tests with simulated SYNCOM I squibs to establish a current-firing delay curve. Each part used consisted of a SYNCOM I firing circuit enclosed in a test squib body (SDI part No. 1J35-5.4). Two squibs were tested at 2 amps and one each at 1 amp intervals up to 10 amps. The delay times from current application to bridgewire break are plotted against current in Fig. A-1. The data points form a smooth curve as expected through 9 amps, but the 10 amp delay time jumps considerably above this curve. Post firing inspection of this part indicated that one of the pin bridgewires had burned through in the presence of air, but the effect of this event on bridge delay time is not known. More tests would be required to determine the validity of this particular test and to evaluate the part-to-part dispersion at different current levels.



SERIAL NUMBER	RESISTANCE ohms	FIRING CURRENT	DELAY TIME m sec
1	1.09	2	745
2	1.12	2	NO FIRE
3	1.10	3	22
4	1.09	4	15
5	1.03	5	8
6	1.06	6	3.5
7	1.12	7	2.1
8	1.07	8	1.2
9	1.01	9	0.7
10	1.03	10	2.6

Fig. A-1. Current-time curve

APPENDIX B

Environmental and Operational Tests

Thirty-six squibs were subjected to the test program outlined in Fig. B-1 to evaluate the effects of temperature shock, vibration, vacuum exposure, and AMR no-fire tests on the squib's mechanical and operational characteristics. Also evaluated were the firing characteristics in vacuum and at ambient pressure over a range of temperatures. The squibs, which are denoted individually by serial number in Fig. B-1, were tested in two groups. Group I consisted of 14 squibs which were tested over the complete range of test conditions to uncover any problem areas which might exist in the squib design and/or the test procedures. Using the results from the Group I tests for planning, 22 squibs were tested in Group II to complete the test program. The Group II tests were set up to give at least three acceptable data points at each temperature in the reference ambient pressure tests, and at least two acceptable data points at each temperature in all other tests.

I. CIRCUIT RESISTANCE AND SHORT TESTS

A. Equipment

The bridge resistances were measured with an Allegheny Instrument Company (Alinco) Igniter Circuit Tester, Model 101-5BF, which has an accuracy of ± 0.02 ohms. A Simpson Model 260 VOM with a maximum reading of 2×10^4 megohms was used to check for possible pin-to-pin or pin-to-body shorts.

B. Procedures

Prior to each series of measurements the Alinco meter was calibrated with a 1 ohm $\pm 0.1\%$ resistor to null out the meter leads. Each squib was placed in a safety chamber, the shorting plug was removed, and a Bendix connector with leads of known resistance was attached. Resistance measurements were then made of circuits A-D and B-C, the values recorded, and the connector lead resistance subtracted from the recorded values to give the corrected resistance readings. Dielectric resistance tests were made across pins A-B and from each pin to the squib body, and the results were recorded. Short tests were also made with the Simpson meter after each firing to check for short circuits which would drain a power supply. Circuits A-D, A-C, B-D, B-C, A-Body, B-Body, C-Body, and D-Body were checked.

C. Results

The initial resistance readings made at JPL were within 0.04 ohms of the values recorded by SDI on all squibs used in the environmental test program except #21B, where a disparity of 0.06 ohms was recorded on one circuit. The succeeding resistance measurements were made to check the effects of various environmental tests, so the results are discussed after each test discussion. Tables B-1 and B-2 summarize the resistance data on all squibs from SDI inspection through firing.

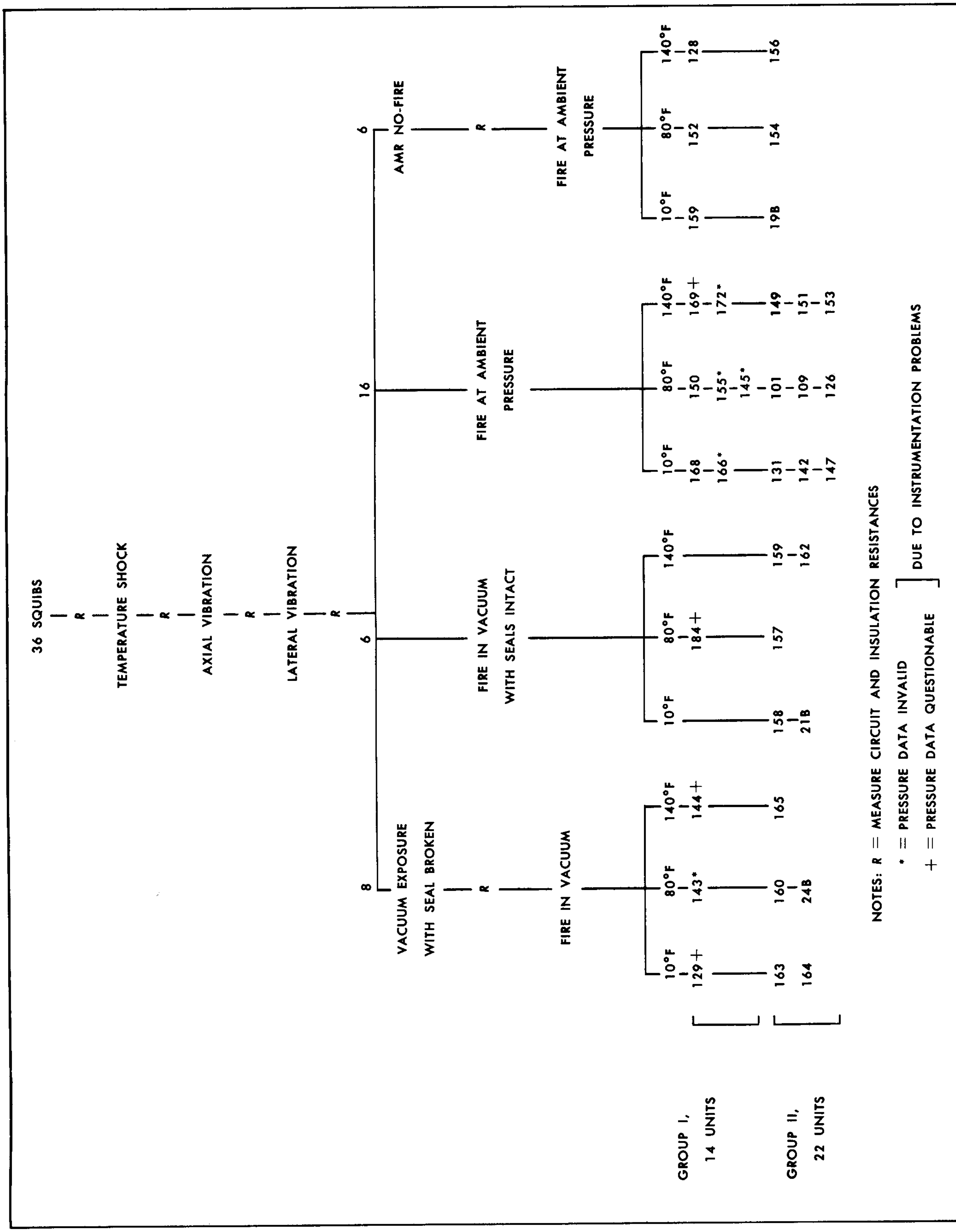


Fig. B-1. Environmental and operational tests

Table B-1. Resistance data; Group I

Serial number	Circuit	SDI	JPL acceptance; May 21	Temp. shock; May 23	Axial vibration; May 24	Lateral vibration; May 24	Vacuum exposure; May 28	AMR no-fire; May 28	After fire; May 28
128	A-D B-C Short	1.16 1.24	1.17 1.23 OK	1.16 1.25 OK	1.18 1.26 OK	1.16 1.25 OK	— — —	1.18 1.27 OK	A-D, 390K B-C, 410K A-Body, 2.5 meg B-Body, 2.5 meg
152	A-D B-C Short	1.36 1.12	1.34 1.08 OK	1.31 1.08 OK	1.34 1.09 OK	1.34 1.09 OK	— — —	1.47 1.09 OK	OK
159	A-D B-C Short	1.17 1.07	1.18 1.08 OK	1.20 1.08 OK	1.12 1.09 OK	1.20 1.08 OK	— — —	1.20 1.09 OK	OK
129	A-D B-C Short	1.05 1.15	1.03 1.15 OK	1.02 1.14 OK	1.03 1.15 OK	1.02 1.14 OK	1.02 1.13 OK	— — —	No data Available (squib stuck in fixture)
143	A-D B-C Short	1.04 1.02	1.03 1.02 OK	1.02 1.02 OK	1.03 1.03 OK	1.04 1.03 OK	1.05 1.04 OK	— — —	A-D, 370K B-C, 420K A-Body, 580K B-Body, 580K
144	A-D B-C Short	1.03 1.08	1.01 1.06 OK	1.05 1.17 OK	1.01 1.10 OK	1.02 1.12 OK	1.00 1.09 OK	— — —	A-D, 48K B-C, 35K A-Body, 160K B-Body, 152K
145	A-D B-C Short	1.02 1.00	1.02 1.00 OK	1.03 1.00 OK	1.03 1.01 OK	1.02 1.01 OK	— — —	— — —	B-C, 3.7 meg
150	A-D B-C Short	1.02 0.94	1.05 0.94 OK	1.04 0.94 OK	1.03 0.94 OK	1.02 0.96 OK	— — —	— — —	OK
155	A-D B-C Short	1.07 1.03	1.07 1.03 OK	1.06 1.02 OK	1.07 1.03 OK	1.06 1.02 OK	— — —	— — —	OK
166	A-D B-C Short	1.02 0.82	1.02 0.83 OK	0.99 0.84 OK	1.01 0.86 OK	1.02 0.87 OK	— — —	— — —	A-B, 1.3 meg A-D, 20 meg B-C, 20 meg A-Body, 20 meg B-Body, 20 meg
168	A-D B-C Short	1.09 1.04	1.09 1.03 OK	1.08 1.01 OK	1.08 1.04 OK	1.08 1.02 OK	— — —	— — —	A-B, 4 meg A-D, 10 meg B-C, 10 meg A-Body, 10 meg B-Body, 10 meg
169	A-D B-C Short	1.02 1.14	0.97 1.14 OK	0.97 1.24 OK	0.96 1.21 OK	0.97 1.21 OK	— — —	— — —	A-B, 7 meg A-D, 730K B-C, 5 meg
172	A-D B-C Short	0.94 1.01	0.95 1.03 OK	0.97 1.00 OK	0.97 1.01 OK	0.96 1.01 OK	— — —	— — —	OK
184	A-D B-C Short	1.02 1.20	1.02 1.20 OK	1.00 1.21 OK	1.01 1.22 OK	1.01 1.21 OK	— — —	— — —	A-B, 48K A-D, 57K B-C, 54K A-Body, 400K B-Body, 730K

Table B-2. Resistance data; Group II

Serial number	Circuit	SDI	JPL acceptance; Aug. 24	Temp. shock; Aug. 27	Axial vibration; Aug. 28	Lateral vibration; Aug. 29	AMR no-fire; Aug. 30	Vacuum exposure; Aug. 31	Short-test comments
101	A-D	1.05	1.08	1.10	1.08	1.08	—	—	OK
	B-C	1.11	1.11	1.10	1.12	1.12	—	—	
109	A-D	1.07	1.05	1.07	1.08	1.07	—	—	OK
	B-C	1.14	1.17	1.16	1.15	1.15	—	—	
126	A-D	1.03	1.02	1.04	1.04	1.02	—	—	OK
	B-C	1.10	1.10	1.10	1.08	1.08	—	—	
131	A-D	1.14	1.13	1.12	1.13	1.14	—	—	OK
	B-C	1.09	1.06	1.07	1.08	1.08	—	—	
142	A-D	1.09	1.08	1.08	1.09	1.09	—	—	After fire
	B-C	1.06	1.05	1.07	1.05	1.06	—	—	A-Body, 500 ohms
									A-D, 2 megohms
147	A-D	1.07	1.06	1.07	1.06	1.08	—	—	OK
	B-C	1.18	1.19	1.20	1.19	1.20	—	—	
149	A-D	1.12	1.11	1.12	1.11	1.12	—	—	OK
	B-C	1.16	1.15	1.14	1.15	1.16	—	—	
151	A-D	1.18	1.16	1.18	1.19	1.16	—	—	OK
	B-C	1.12	1.12	1.12	1.10	1.11	—	—	
153	A-D	1.02	1.02	1.04	1.02	1.01	—	—	OK
	B-C	1.03	1.02	1.05	1.03	1.03	—	—	
154	A-D	1.13	1.14	1.14	1.13	1.13	1.15	—	OK
	B-C	1.03	1.02	1.03	1.03	1.02	1.02	—	
156	A-D	1.15	1.15	1.15	1.14	1.14	1.15	—	OK
	B-C	1.09	1.07	1.10	1.07	1.08	1.09	—	
19B	A-D	1.08	1.08	1.08	1.09	1.09	1.08	—	OK
	B-C	1.08	1.09	1.08	1.06	1.08	1.06	—	
157	A-D	1.09	1.10	1.10	1.09	1.08	—	—	OK
	B-C	1.12	1.12	1.12	1.11	1.11	—	—	
158	A-D	1.13	1.11	1.14	1.13	1.14	—	—	OK
	B-C	1.11	1.10	1.11	1.09	1.10	—	—	
159	A-D	1.15	1.15	1.16	1.15	1.16	—	—	OK
	B-C	1.15	1.14	1.16	1.15	1.16	—	—	
162	A-D	1.06	1.06	1.06	1.07	1.06	—	—	OK
	B-C	1.12	1.10	1.11	1.11	1.11	—	—	
21B	A-D	1.13	1.12	1.12	1.12	1.12	—	—	OK
	B-C	1.14	1.20	1.19	1.19	1.19	—	—	
160	A-D	1.09	1.12	1.10	1.09	1.11	—	1.09	OK
	B-C	1.18	1.17	1.17	1.16	1.17	—	1.17	
163	A-D	1.13	1.14	1.13	1.13	1.14	—	1.15	OK
	B-C	1.03	1.01	1.00	1.00	0.99	—	0.99	
164	A-D	1.09	1.11	1.10	1.09	1.09	—	1.09	OK
	B-C	1.12	1.13	1.13	1.11	1.11	—	1.12	
165	A-D	0.98	0.97	0.98	1.00	0.98	—	1.01	OK
	B-C	1.06	1.09	1.05	1.06	1.05	—	1.04	
24B	A-D	1.06	1.07	1.05	1.06	1.07	—	1.07	OK
	B-C	1.14	1.13	1.15	1.15	1.15	—	1.15	

II. TEMPERATURE SHOCK TESTS

A. Equipment

Two Bemco temperature-test chambers were used for the temperature shock tests. The cold tests were carried out in a 2 cubic ft, liquid nitrogen cooled chamber located in JPL Bldg. No. 144, while the hot tests were conducted in a 1 cubic ft, electrically heated, portable unit also located in Bldg. 144. Each unit produced temperatures accurate to within $\pm 2°F$. Figure B-2 shows the two chambers in operation.

B. Procedures

The cold chamber was cooled to $-65°F$, and the hot chamber was heated to 165°F prior to the test. The squibs were placed in a pan and inserted into the cold chamber after it had reached $-65°F$. An hour later the squibs were removed from the cold chamber and immediately placed in the hot chamber. Following one hour of exposure to heat, the procedure was reversed and the squibs were placed in the cold chamber for another hour of exposure. The squibs were then removed, allowed to reach ambient temperature, and inspected for changes in exterior appearance and/or circuit resistance.

C. Results

The squibs passed the temperature shock tests satisfactorily. All the seals were still intact, and no short circuits were recorded. The B-C circuits of squibs 144

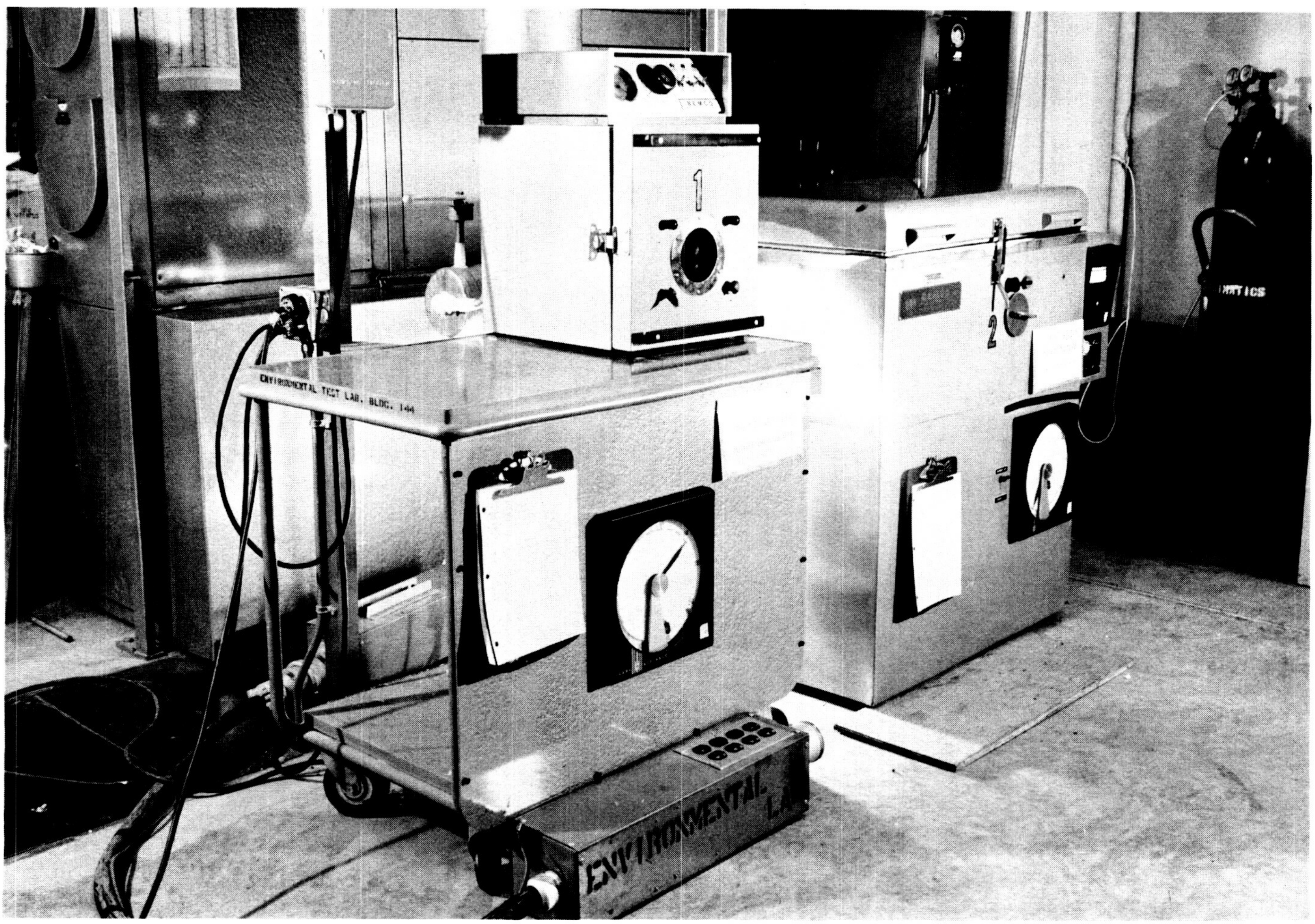


Fig. B-2. Temperature shock test equipment and 169 used in Group I rose about 0.1 ohm after the temperature shock tests, but this was not considered to be a critical result. The internal portions of the pins used in the Group I squibs were not masked during plating; this led to circuit-resistance control problems in manufacture and might possibly have precipitated the resistance instability of these two units. All of the rest of the Group I temperature shock measurements and all from Group II fell within the accuracy limits of the Alinco meter.

III. VIBRATION TESTS

A. Equipment

The Group I squibs were vibrated on vibration tables MBC 70 (a 7000 lb vibration exciter) and MBC 25H (a 3500 lb vibration exciter) in JPL Bldg. No. 82. Two MBC 25HB tables of 5000 lb capacity located in Bldg. 144 were used for the Group II tests. The Group II vibration tables are shown in Fig. B-3; the squibs are set up on the vertical vibration table to the left of the picture.

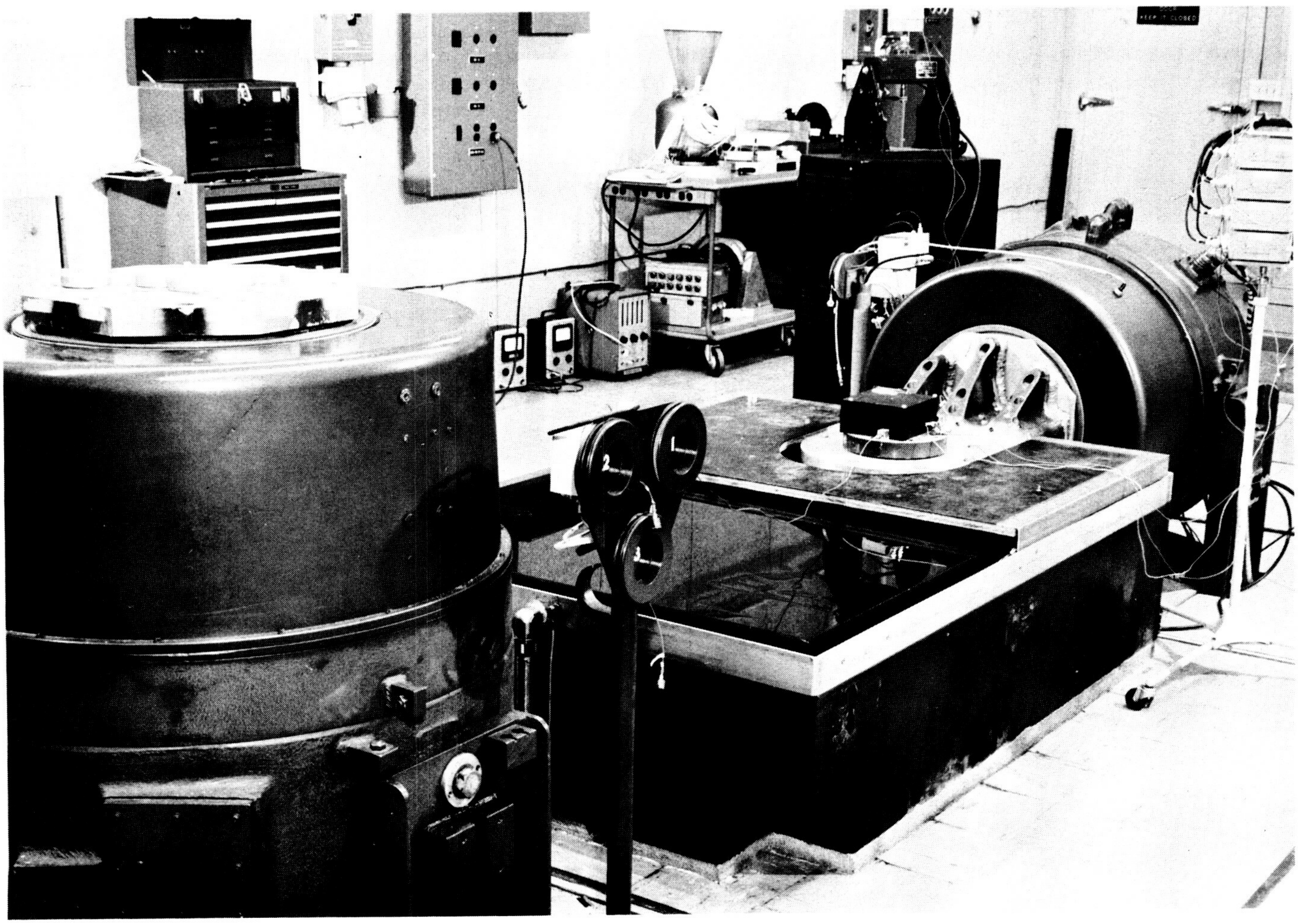


Fig. B-3. Vibration test equipment

B. Procedures

All squib vibration tests were conducted after 5:00 p.m. because of safety requirements. The squibs were mounted, six at a time, on the vertical table by the use of a special fixture. Figure B-4 illustrates the mounting arrangement which was designed to completely enclose the loaded end of each squib. The squibs were vibrated along the symmetrical axis according to program A in Table B-3. Resistance and short checks were made after the longitudinal vibration. The squibs were vibrated on the horizontal table according to program B of Table B-3, and the resistance and short tests were repeated.

C. Results

No discrepancies were recorded after either axial or lateral vibration. The squibs appeared structurally sound and no short circuits were recorded. All resistance variations in both groups were within the accuracy of the meter.

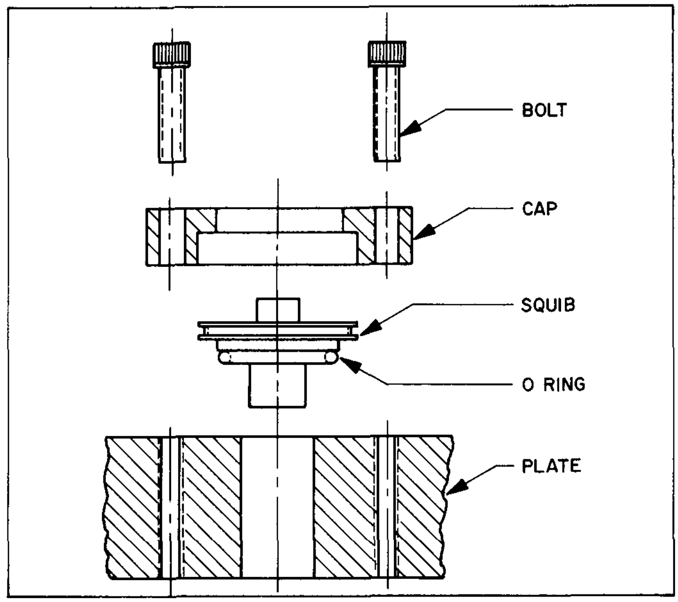


Fig. B-4. Vibration fixture design

Table B-3. Vibration test program

Direction	Mode	Duration	Frequency range, cps	Acceleration
A. Along the squib's symmetric axis	Sinusoidal	5-min logarithmic sweep	10-50	1.5g rms
			50-250	7.5g rms
			250-300	18.75g rms
			300-500	7.5g rms
			500-2000	15.0g rms
	Resonance	30-sec linear sweep	550-650	40g rms
	Random	4 min	20-2000	0.07g^2/cps
B. Perpendicular to the squib's symmetric axis	Sinusoidal	5-min logarithmic sweep	5-25	0.6g rms
			25-30	3.06g rms
			30-50	0.6g rms
			50-500	1.5g rms
			500-2000	3.0g rms
	Resonance	30-sec linear sweep	550-650	40g rms
	Random	4 min	20-2000	0.07g^2/cps

IV. VACUUM EXPOSURE TESTS

A. Equipment

The vacuum exposure tests were carried out in CVC glass bell jar No. 1 located in JPL Bldg. No. 82. The bell jar has a test chamber 18 in. in diam by 30 in. high. It is capable of an ultimate pressure of 2×10^{-6} mm Hg absolute. Figure B-5 is a photograph of an identical piece of test equipment.

B. Procedures

The aft seal, closure, and mica disc of eight squibs were punctured with a scribe for the vacuum exposure tests. The squibs were placed into the bell jar in a pan and subjected to a vacuum of 10^{-5} mm Hg for 5 hours at ambient temperature. After the vacuum exposure, resistance and short tests were conducted.

C. Results

No changes in electrical characteristics were recorded after the vacuum exposure tests.

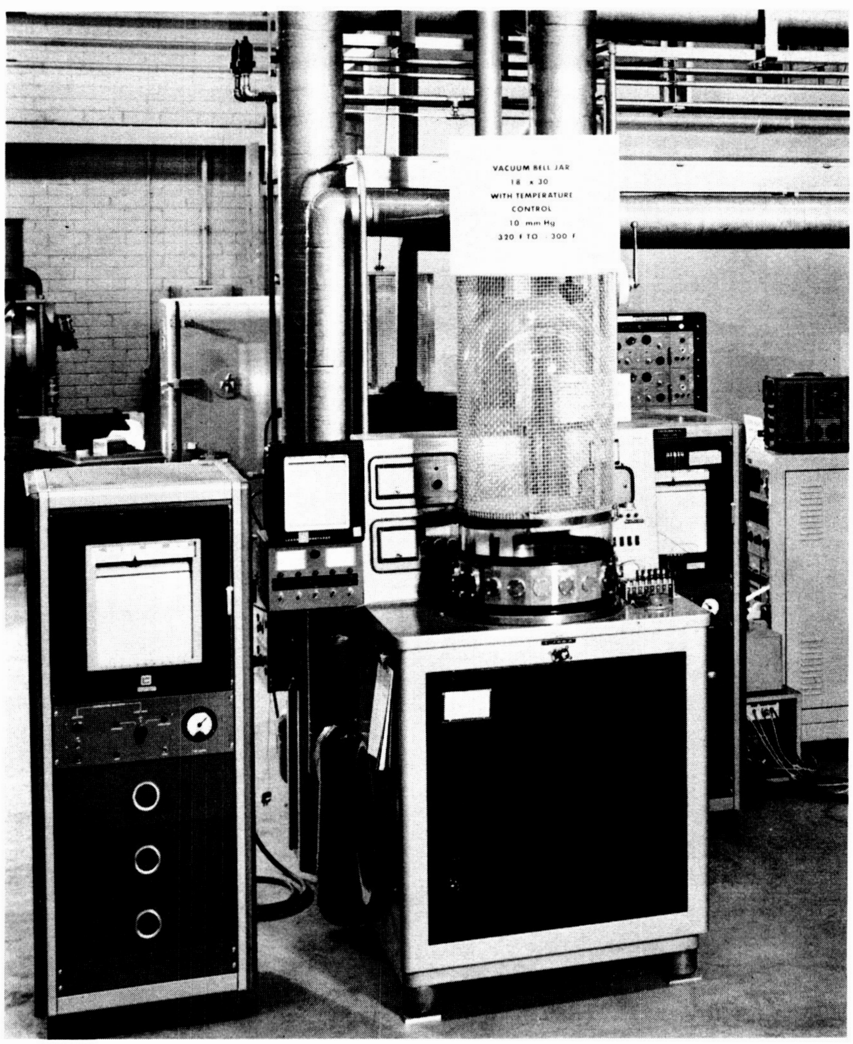
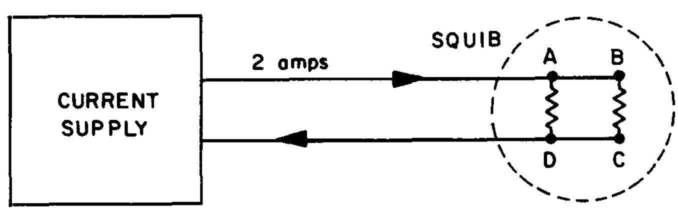


Fig. B-5. Vacuum exposure test equipment

V. AMR NO-FIRE TESTS

A. Equipment

The AMR no-fire tests were performed using the JPL *Mariner* squib firing system which consists of a constant current generator run by a DC power supply. It is rated at 0–30 amps with an accuracy of ±0.1%. At the resistances encountered in the SYNCOM I squib, however, the maximum current output was about 5 amps.



Sketch B-1

B. Procedures

The squibs used for this test series were placed in a safety chamber and connected to the current generator as shown in Sketch B-1. A current of 2 amps was passed through each squib for 5 min, after which the bridgewire resistance and insulation characteristics were checked.

C. Results

None of the 6 squibs subjected to the AMR no-fire test fired. Post-test resistance measurements showed that the resistance of circuit A-D of squib 152 jumped from 1.34 to 1.47 ohms. This could have been brought about by an unstable connection as discussed in the temperature shock results. Here again the change was not radical.

VI. SQUIB FIRINGS

A. Equipment

The squib-firing test equipment is shown schematically in Fig. B-6, while Fig. B-7 is a photograph of the test area in JPL Bldg. 82. Following are discussions of the individual instruments used for the firing tests.

1. Temperature Control

The squib firing temperature was controlled by a Conrad, dual tank, water-glycol, temperature control bath which is shown on the left side of Fig. B-7. This instrument has a temperature range of −20°F to +200°F with a probable gauge accuracy of ±5°F. The two reservoirs can be used simultaneously at different temperature levels.

2. Temperature Monitor

A copper-constantan thermocouple was used in conjunction with a Northrop potentiometer to monitor squib temperatures. The instrument is shown at the rear of the test table in Fig. B-7.

3. Vacuum

A Veeco Model MS-9 leak detector was used to pull a vacuum on the test fixtures prior to the vacuum firings. The system, which is shown in the foreground of Fig. B-7, drew a vacuum of 5×10^{-5} mm Hg abs.

4. Instrumentation

The JPL *Mariner* squib-firing system shown in the right background of Fig. B-7 was used for the squib firings. This unit, which was described under the AMR no-fire test discussion, provided a constant firing current and also served as contact panel for the 500-lb Taber pressure transducer. Current and pressure channels on the panel were connected to a Consolidated Electrodynamics Corporation Model 5-119 oscillograph in the JPL Central Recording System. This instrument recorded current and pressure-time curves with a built-in photographic system at a speed of 100 in. per sec. A Sanborn single-channel recorder was also used to give an immediate pressure readout on the Group II firings.

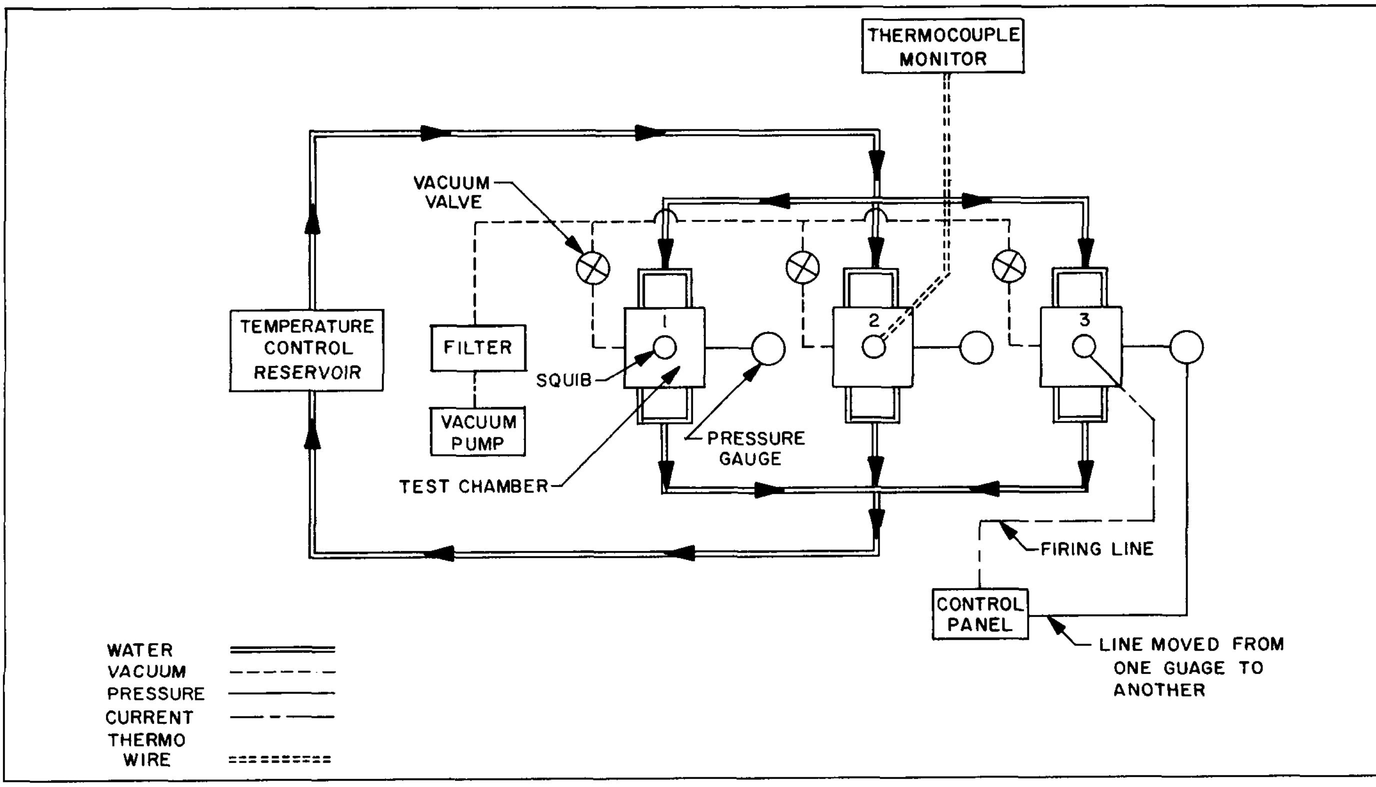


Fig. B-6. Firing equipment schematic diagram

5. Test Chambers

Three 1.77-in.[3] test chambers were designed and fabricated for the JPL program. Each chamber has four temperature control passages through the outer body as well as two ports in the chamber well for pressure gauge and vacuum pump. Figure B-8 is a sketch showing the chamber design. The test chamber complex (temperature control, vacuum, and pressure gauge lines in place) is shown in Fig. B-9.

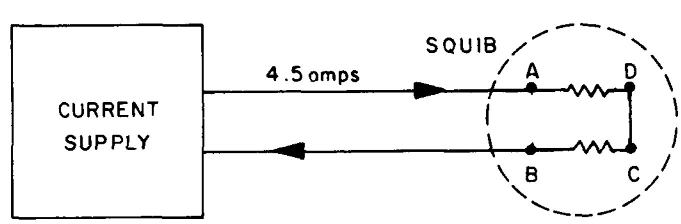
B. Procedures

The procedures used in firing the squibs varied somewhat from test to test. The squibs were generally tested in groups of three at a given temperature level. Other than this the sequence of testing was set up primarily to minimize the time and energy involved in getting from one test series to the next. The two temperature baths were brought to temperature before the testing started, one at 10°F and the other at 140°F. This allowed the equipment to be set up at ambient temperature, fired at a temperature extreme, and returned to ambient temperature for rehandling with a minimum of waiting time.

The firing console was not capable of producing the nominal 9-amp firing current through a parallel circuit, so a 4.5-amp series circuit was used. Calculations showed that the difference in total power dissipation between the series and parallel circuits would be within 0.5% and would have a negligible effect on firing characteristics. Sketch B-2 shows the series-circuit diagram.

The following is a typical list of procedures for a single vacuum firing at 140°F. Possible alternatives are listed where applicable.

1. Coat inside of chamber with silicone grease.
2. Insert squib and thermocouple.



Sketch B-2

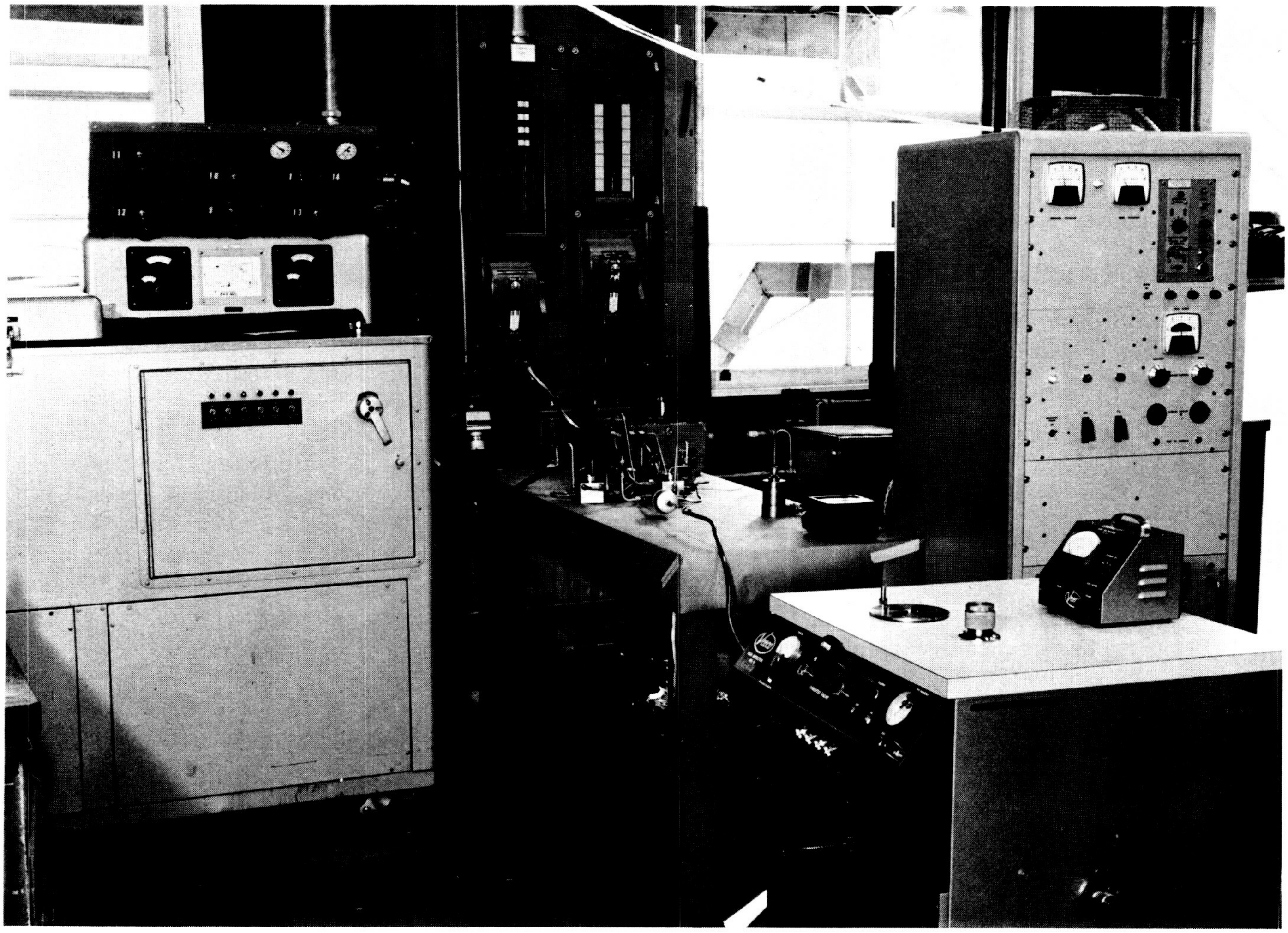


Fig. B-7. Firing equipment

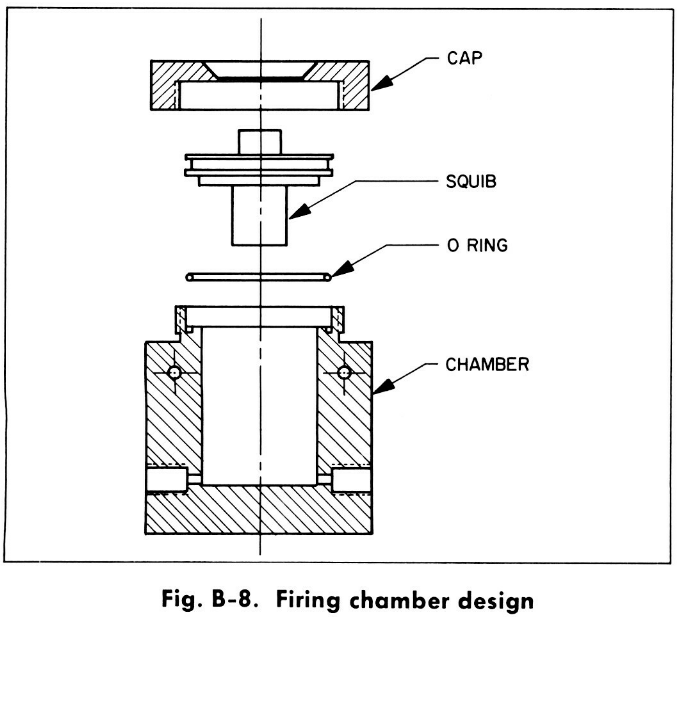


Fig. B-8. Firing chamber design

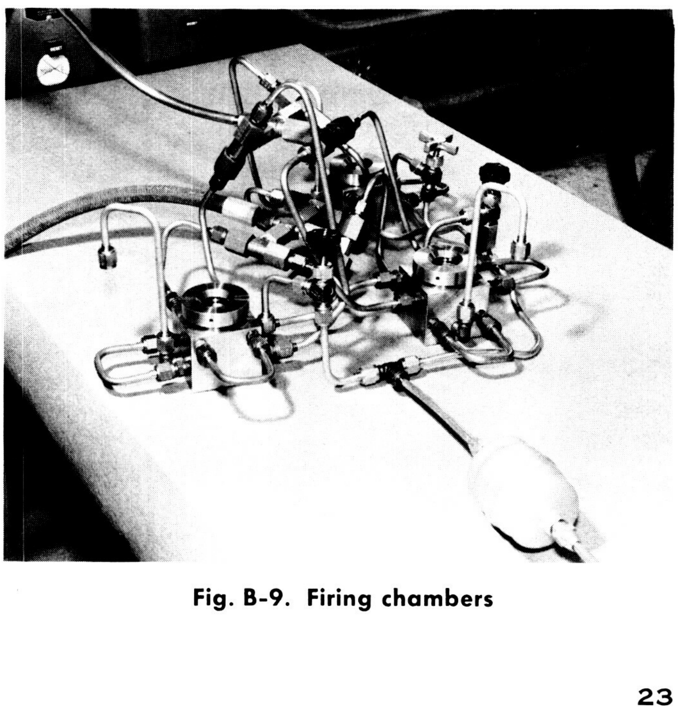


Fig. B-9. Firing chambers

3. Calibrate pressure transducer to 400 psi in 100 psi intervals (recheck every three firings).
4. Calibrate current output at 4.5 amps (recheck every three firings).
5. Attach pressure transducer.
6. Raise apparatus to 140°F.
7. Pull vacuum on chamber.
8. Close valve to prevent pressure surge on vacuum chamber. (Valve is always closed for ambient pressure firings.)
9. Attach lead wire.
10. Turn on recorder.
11. Fire squib.
12. Turn off recorder.
13. Open valve to release pressure.
14. Remove pressure transducer, wipe clean, and refill with oil.
15. Run water through system to bring apparatus to ambient temperature.
16. Remove squib.
17. Clean chamber and pressure line with acetone and air hose.
18. Check for post-fire short-circuiting across pins or from pin to body.

C. *Results*

1. Group I

Figure B-10 is a typical oscillograph trace which illustrates the current and pressure history of a squib and defines the time intervals of interest. Tables B-4 and B-5 present the peak pressures and delay times obtained from the firings where such data were available. A clogged pressure line which was not discovered until after the firings were completed caused inaccurate pressure-time curves on tests 6, 9, 10, 12, and 14. In addition, it is probable that the long, highly damped, pressure rise curves recorded in tests 3, 5, 7, and 13 were due to partially clogged lines, although the peak pressures recorded in these tests are not greatly inconsistent with the other data.

Six squibs showed post fire resistances of less than 2 megohms across one or more desirably-open circuits. It was determined that these shorts were caused by carbon

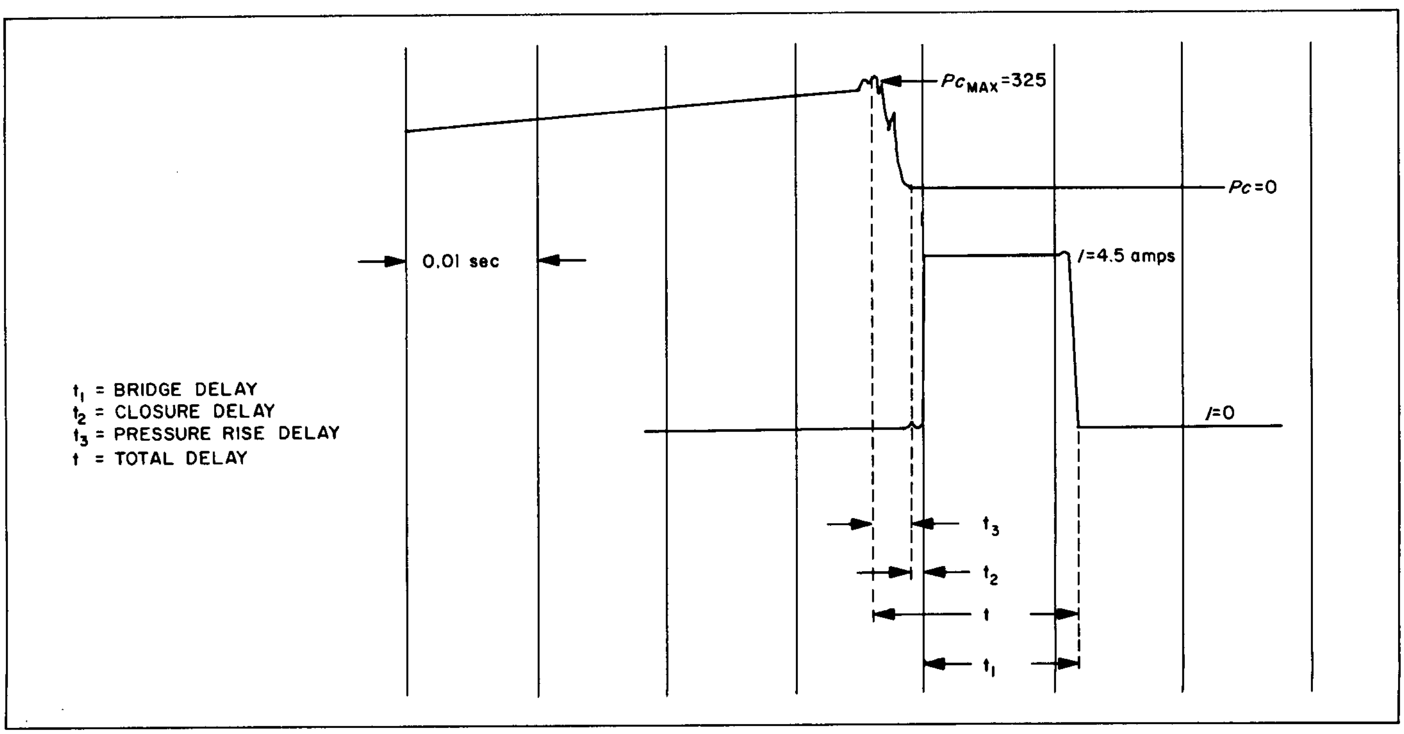


Fig. B-10. Sample current-pressure record

Table B-4. Firing data; Group I

Test description	Temperature °F	Test number	Serial number	Maximum pressure	Bridge delay (t_1) millisec	Closure delay (t_2) millisec	Pressure rise delay (t_3) millisec	Total delay (t) millisec
Reference tests	10	11	168	305	12.3	1.1	3.3	16.7
		12	166	—[a]	13.4	—[a]	—[a]	—[a]
	80	8	150	330	12.2	1.4	3.6	17.2
		9	155	—[a]	9.0	—[a]	—[a]	—[a]
		10	145	—[a]	12.3	—[a]	—[a]	—[a]
	140	13	169	270[b]	10.4	2.8	8.4[b]	21.6[b]
		14	172	—[a]	10.4	—[a]	—[a]	—[a]
Vacuum firing with seal intact	80	7	184	240	12.4	2.1	11.5[b]	26.0[b]
Vacuum firings with seal broken after 5 hr of vacuum exposure	10	3	129	170	14.4	4.2	14.9[b]	33.5[b]
	80	6	143	—[a]	10.7	—[a]	—[a]	—[a]
	140	5	144	275	11.3	2.4	11.6[b]	25.3[b]
Ambient pressure after AMR no-fire test	10	2	159	325	12.5	0.6	3.5	16.6
	80	1	152	325	11.1	1.7	2.1	14.9
	140	4	128	355	11.4	2.5	5.1	19.0

[a] Data unavailable due to clogged pressure line.
[b] Data questionable.

Table B-5. Firing data; Group II

Test description	Temperature °F	Test number	Serial number	Maximum pressure	Bridge delay (t_1) millisec	Closure delay (t_2) millisec	Pressure rise delay (t_3) millisec	Total delay (t) millisec
Reference tests	10	18	131	290	12.4	1.0	3.4	16.8
		19	142	305	12.7	0.8	2.4	15.9
		20	147	310	13.6	2.4	2.3	18.3
	80	15	101	280	12.4	0.8	2.2	15.4
		16	109	325	12.1	0.9	1.9	14.9
		17	126	295	13.3	0.8	1.9	16.0
	140	21	149	310	10.8	1.1	2.7	14.6
		22	151	330	11.8	0.9	2.9	15.6
		23	153	310	11.6	1.5	2.5	15.6
Vacuum firings with seal intact	10	27	158	175	16.5	8.0	3.2	27.7
		28	21B	175	13.4	3.9	3.4	20.7
	80	24	157	190	12.9	1.7	2.7	17.3
	140	30	159	210	12.8	2.9	3.4	19.1
		31	162	210	13.6	2.5	3.3	19.4
Vacuum firings with seal broken after 5 hr of vacuum exposure	10	34	163	185	13.0	3.4	2.8	19.2
		35	164	175	12.0	2.1	3.6	17.7
	80	32	160	200	10.9	2.9	1.7	15.5
		33	24B	210	11.0	3.0	2.7	16.7
	140	36	165	230	9.9	4.0	2.4	16.3
Ambient pressure after AMR no-fire test	10	26	19B	320	14.2	1.5	1.7	17.4
	80	25	154	315	12.8	1.0	2.0	15.8
	140	29	156	320	12.1	2.5	2.3	16.9

coatings over the pin ends. Such carbon deposits are burned away in full-scale motor firings, so the measurements on these squibs do not give a true indication of characteristics.

2. Group II

Pressure lines having an inside diameter of 0.18 in. were substituted for the 0.06-in. ID lines in the Group II tests. This solved the clogging problem, and the tests yielded a consistent set of data at the expense of slightly less damping in the pressure curves. As shown in Table B-5, the only significant variation in data occurred in Test 27, where the recorded time of 8 msec between bridgebreak and pressure rise was twice as long as any other Group I or II test. The normal peak pressure and pressure-rise time seem to indicate that the instrumentation was operating satisfactorily. It is possible that the charge of this squib was not loaded compactly and that a void existed around one of the bridgewires, thereby slowing down the primer-main charge reaction time.

Of the 22 squibs tested in Group II, only No. 142 showed the carbon-coating shorts recorded more frequently in Group I.

3. General Conclusions

a. The peak pressure increased slightly with temperature as would be expected.

b. Bridgebreak and over-all delay times were very consistent and did not seem to be affected by temperature variations.

1. Bridgebreak on all tests: 9 to 14.4 msec; average 12.2 msec.

2. Total delay on all but questionable Group I tests: 14.6 to 27.7 msec; average 17.3 msec.

c. Squibs subjected to vacuum exposure with seals broken demonstrated characteristics identical to those fired into a vacuum with no alteration. The peak pressure differential of about 100 psi between vacuum and ambient tests was due to the heating of the air trapped in the chamber during the ambient tests.

d. The AMR no-fire tests had no identifiable effects on the squib operating characteristics.

APPENDIX C

Bruceton Analysis

I. OBJECTIVE

Special Devices, Incorporated, subjected 21 squibs to the test sequence outlined in Fig. C-1. The test objectives were two-fold:

1. To evaluate all-fire–no-fire characteristics.
2. To evaluate the effect of no-fire tests on firing characteristics.

21 SQUIBS

INITIAL RESISTANCE MEASUREMENT

TEMPERATURE SHOCK

JOLT

RESISTANCE

VIBRATION

RESISTANCE

BRUCETON TEST

BRIDGEBREAK TIME TESTS
(UNITS WHICH DID NOT FIRE IN BRUCETON TEST)

Fig. C-1. Bruceton analysis test sequence

II. ENVIRONMENTAL TESTS

The temperature shock and jolt tests were carried out by SDI—the temperature shock tests as described in Appendix B, and the jolt tests according to MIL-STD-350. JPL performed the vibration tests as described in Appendix B. None of these tests had any detrimental effects on the squib resistances or flight mechanical structure, although five pressure taps broke from static test squibs during the jolt test. These units, which are identical to the flight squibs except for two pressure taps attached to the squib flange, were not designed to withstand such tests. Table C-1 presents a summary of the data from these environmental tests.

Table C-1. Bruceton sequence test data

Serial number	Resistance circuit A-D, ohms	Resistance circuit B-C, ohms	−65° F, 1 hr	+165° F, 1 hr	−65° F, 1 hr	Jolt	Bridge resistance, ohms	Missile vibration	Bridge resistance, ohms	Bruceton	Bridge break at 4.5 amp millisec
132	—	1.08	OK	OK	OK	OK	1.09	OK	1.08	Fire	—
134	1.17	—	OK	OK	OK	OK	1.17	OK	1.17	—	No fire*
139	1.13	—	OK	OK	OK	OK	1.17	OK	1.15	Fire	—
136	1.13	—	OK	OK	OK	OK	1.15	OK	1.12	—	21.5
141	—	1.13	OK	OK	OK	OK	1.15	OK	1.15	—	4.0
140	1.19	—	OK	OK	OK	OK	1.20	OK	1.19	—	16.0
179	—	1.00	OK	OK	OK	OK	1.03	OK	1.05	Fire	—
183	1.01	—	OK	OK	OK	OK	1.03	OK	0.99	—	14.0
175	1.01	—	OK	OK	OK	OK	1.01	OK	0.99	Fire	—
108	1.15	—	OK	OK	OK	OK	1.17	OK	1.13	—	27.0
107	1.06	—	OK	OK	OK	OK	1.07	OK	1.05	—	14.9
100	1.06	—	OK	OK	OK	OK	1.06	OK	1.05	Fire	—
171	—	0.99	OK	OK	OK	OK	0.99	OK	0.99	Fire	—
176	—	0.88	OK	OK	OK	OK	0.94	OK	0.86	Fire	—
211	1.14	—	OK	OK	OK	Tap broke	1.16	OK	1.14	—	14.0
214	—	1.12	OK	OK	OK	Tap broke	1.14	OK	1.13	Fire	—
219	1.13	—	OK	OK	OK	Tap broke	1.16	OK	1.17	Fire	—
212	1.13	—	OK	OK	OK	Tap broke	1.15	OK	1.15	—	14.0
122	1.06	—	OK	OK	OK	OK	1.07	OK	1.06	—	15.0
205	1.21	—	OK	OK	OK	Tap broke	1.20	OK	1.18	—	22.0
181	1.11	—	OK	OK	OK	OK	1.11	OK	1.11	Fire	—

*Bridge was broken.

III. BRUCETON ANALYSIS TEST

A. Equipment

The Bruceton analysis test was performed utilizing an SDI test set (No. 200786) calibrated every two months. The Bruceton test set consists of a metered variable resistance circuit operated from the central 28 v source and capable of being adjusted in increments of 0.05 amps. The system is calibrated to a claimed accuracy of 1%.

B. Procedure

The standard Bruceton analysis techniques (Ref. 1) were utilized which consist briefly of the following:

1. A group of five shots was made to establish expected median and distribution.
2. When the information, in No. 1 above, had been obtained, the units were fired in a sequential manner at varying current levels as indicated in Table C-2.

C. Results

The Bruceton series was extremely satisfactory. An interval of 0.1 amps was chosen with assumed median of 1.8 amps. Upon completion of the test and reduction of data, the median was found to be 1.86 amps, with a standard deviation of 0.116 amps.

The raw data and SDI computations are presented in Table C-2. JPL computations* show the 99.9% reliable, 95% confidence level, minimum no-fire values of 1.25 amps and 1.56 watts per squib circuit. By the same method the 99.9% reliable, 95% confidence level all-fire current is 2.47 amps per squib circuit.

The no-fire levels quoted above could be slightly high due to the use of only one firing circuit in each squib. The tests were approved in this form, however, because there were not enough squibs with two good circuits available at the time the tests were performed. The results of the AMR no-fire tests discussed in Appendix B tend to add credence to the data; six squibs were subjected to 2 amps in parallel for 5 minutes with no firings recorded.

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*From SDI Test:

$$\bar{X} = 1.86 \text{ amp}$$
$$\sigma = 0.116 \text{ amp}$$

The maximum no-fire current is given by

$$I_N = \bar{X} - t\,\sigma$$

where t equals 5.29 for a 99.9% reliable, 95% confidence level no-fire estimate with the sample size used (Ref. 2).
Therefore:

$$I_N = 1.25 \text{ amps per squib circuit.}$$

Since the minimum circuit resistance is one ohm, the maximum no-fire power dissipation at the above reliability and confidence levels is at least 1.56 watts.

Table C-2. Bruceton Test[a]

Raw data

Serial number		212	141	219	181	214	183	176	211	134	136	139	122	132	179	175	140	205	171	108	107	100
L	Amperes																					
$K + 3d$	2.1																					
$K + 2d$	2.0			X								X		X								X
$K + 1d$	1.9		O		X						O		O		X				X		O	
K	1.8	O				X		X		O						X		O		O		
$K - 1d$	1.7						O		O								O					
$K - 2d$	1.6																					

Computations[b]

L	i	X	O	in_i	i^2n_i
$K - 1d$	0	0	3	0	0
K	1	3	4	3	3
$K + 1d$	2	3	4	6	12
$K + 2d$	3	4	0	12	36
$K + 3d$	4	0	0	0	0
Total		10	11	$A = 21$	$B = 51$

$$\bar{X} = c + d\left[(A/n) - \tfrac{1}{2}\right]$$
$$n = 10$$
$$c = K - 1d$$
$$d = 0.1 \text{ amp}$$
$$\bar{X} = 1.86 \text{ amp}$$
$$M = (nB - A^2)/n^2$$
$$M = 0.69$$
$$\text{Tabular } s = 1.16$$
$$\sigma = sd = 0.116 \text{ amp}$$

[a] Tests and computations directed by W. F. Green of SDI.
[b] Squib firing data (denoted by X in data table above) was used for computations.

IV. BRIDGEBREAK TIME TESTS

A. Equipment

The bridgebreak time test was performed using an SDI-fabricated firing console (No. 200750) in conjunction with Tektronix oscilloscope No. 551. The firing current pulse was monitored using a Dumont polaroid oscilloscope camera.

B. Procedure

Those units which failed to fire in the Bruceton test and retained continuity were attached to the firing console leads after the firing console had been adjusted to produce 4.5 amps. The firing console was provided with a series resistance pickup so that a voltage analog of firing current could be displayed on the oscilloscope. A photograph was taken of the current versus time trace thus produced. The photograph was then measured from current rise to current drop and this measurement was recorded as bridgebreak time.

C. Results

As was expected, 50% of the units did not fire in the Bruceton test. These units, therefore, were fired at 4.5 amps to obtain some information as to firing time. Eleven units were subjected to the 4.5 amp test. One unit had an open bridge and ten units fired. The firing circuit of squib 134, which did not fire, broke during the Bruceton test. Of the ten other squibs, the firing-delay spread was 4 to 27 msec, and the average and most probable point was around 15 msec. It should be pointed out, however, that all ten of these units had been exposed to current approaching their firing point and did not, therefore, present a necessarily true picture of bridgebreak time.

APPENDIX D

Flight Acceptance Program

After completion of the qualification program, 25 squibs were purchased for possible flight application. Ten of these were used for cable assembly fabrication, but a change in the cable length and connector geometry caused these to be rejected. Eight more cable assemblies were fabricated: one of these was rejected because of a non-grounded shield, and two were used for cable assembly qualification and squib batch-check tests. This left five squib-cable assemblies approved for flight, seven of the flight squib order left untouched, and two flight-type squibs left from the qualification tests.

Figure D-1 is a flow chart showing each step in the squib-cable assembly manufacture and testing sequence. Table D-1 shows the inspection data for the eight squibs fabricated in the final cable-assembly configuration. The disposition of these units is shown in the right hand column, the number beside the flight items representing the preferential order of use. Following are summaries of the individual inspection procedures and results.

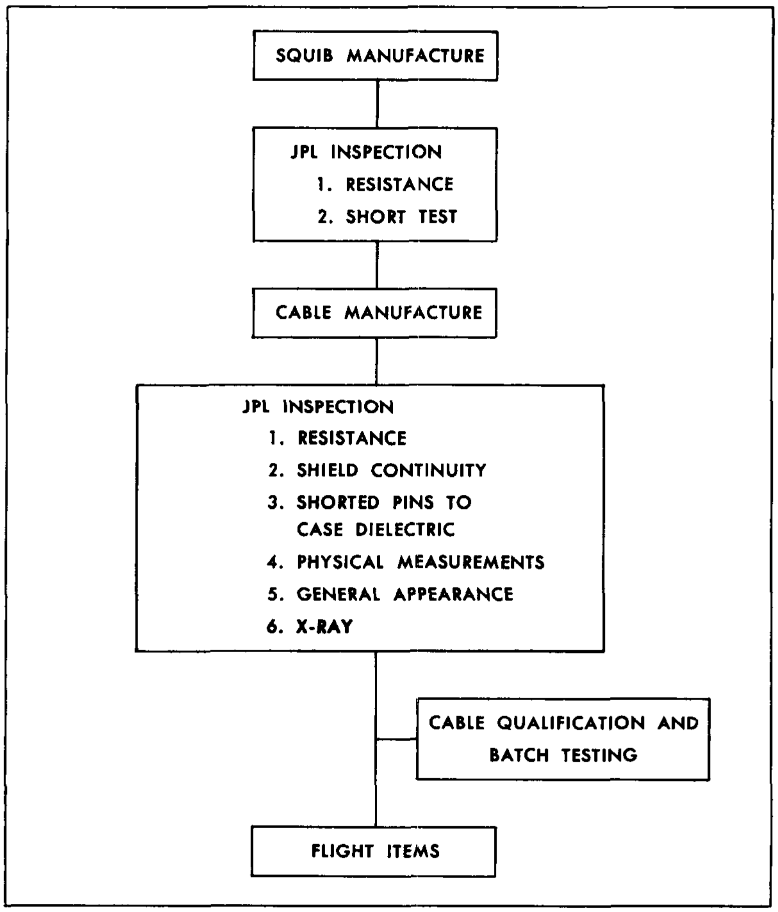


Fig. D-1. Flight squib selection sequence

Table D-1. Flight squib inspection data

Serial number	SDI resistances ohms		JPL squib inspection				JPL squib-cable assembly inspection							Disposition
			Resistances ohms		Short	Calculated assembly resistance ohms	Assembly resistance ohms	Shield continuity	Dielectric strength megohms	Physical dimensions	General appearance	Weight grams	X-ray	
	A-D	B-C	A-D	B-C										
401	1.235	1.145	1.23	1.16	OK	0.63	0.62	OK	5000	OK	Broken seal	77.92	OK	Used for test
402	1.09	1.025	1.09	1.03	OK	0.56	0.55	OK	500	OK	Potting on seal	78.47	OK	Flight; 3rd choice
425	1.115	1.205	1.11	1.21	OK	0.61	0.61	OK	1800	OK	OK	77.62	OK	Fight; 1st choice
427	1.135	1.22	1.13	1.20	OK	0.62	0.62	OK	10^6	OK	OK	79.04	Void	Flight; 4th choice
429	1.10	1.11	1.08	1.12	OK	0.58	0.59	OK	2500	OK	Potting on seal	78.10	Void	Used for test
430	1.14	1.08	1.14	1.09	OK	0.59	0.60	OK	80×10^4	OK	OK	77.93	Void	Flight; 5th choice
431	1.205	1.27	1.20	1.26	OK	0.65	0.65	Open	20×10^4	OK	OK	—	—	Fired and used for dummy
432	1.23	1.10	1.23	1.10	OK	0.62	0.61	OK	9×10^4	OK	OK	77.89	OK	Flight; 2nd choice

I. JPL SQUIB INSPECTION

Squib circuit resistance measurements and dielectric checks were made using the same equipment and procedures described in Appendix B. The measured resistance all coincided within meter accuracy to the values provided by SDI.

II. JPL SQUIB-CABLE ASSEMBLY INSPECTION

A. Circuit Resistance

A predicted assembly resistance was calculated for each squib by using the JPL measured circuit resistances and adding 0.07 ohms to each circuit to account for the cable resistance. The total assembly resistances were then measured with the Alinco circuit tester and the values compared to the calculated values. In all cases the values coincided to within 0.01 ohm.

B. Shield Continuity

A Simpson VOM was used to check the shield grounding by passing a current from the squib body to the connector body. Squib 431 recorded an open circuit. It was discovered that a non-grounded, connector-cable assembly sample had been mistakenly substituted for a production item during the cable manufacturing.

C. Dielectric Test

A 500 VDC Megpot (Model No. 5623) manufactured by the Hermatronics Division of Hermetic Seals Corporation was used to measure the dielectric strength of the squib-cable assemblies. Pins 1 and 2 were shorted together, and the measurement was made between the shorted pins and the squib body. The assemblies all passed this test, measuring from 500 to 10^6 megohms.

D. Physical Dimensions

The cable length and the height of the connector with shorting plug were checked. All units met the specifications of 15.5 $\pm$ 0.25 in. and 0.75 in. max, respectively.

E. General Appearance

Two of the squibs had epoxy on the Poly-Ep seal, and on a third, the seal had been broken. On all further units the seal should be masked to prevent handling damage during the cable assembly manufacture.

All but one of the squibs had a slight amount of epoxy on the nut bearing surface which was caused by variations in the squib flange thickness. This epoxy was easily removed with a razor blade.

F. X-Ray

Seven of the flight squibs were X-rayed at Cal-Ray X-Ray in Santa Ana to confirm loading and bridge wire beading. The squibs were supported with the loaded end pointed downward and shots were taken from two positions 90 deg apart. Table D-2 describes the equipment and technique used for the X-rays.

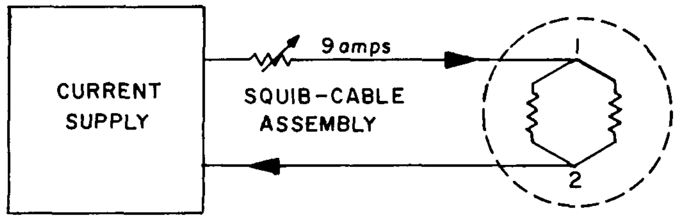
All of the units were loaded, but the X-ray revealed that the mica disc had not been cemented compactly upon the charge of three units, thereby leaving a small void. In none of these units, however, was the void considered large enough to affect the reliability of the squib.

Table D-2. X-ray technique (Cal-Ray No. 145)

Kilovolts	135
Milliamps	12.5
Time, sec	90.0
Distance, in.	61
Tube angle	90 deg
Tube	beryllium
Size of film	8 $\times$ 10
Type of film	B
Lead screen, in.	0.005
Lead backing, in.	0.005
Development	5 min; 68° F
Tube selector position	E scale, large focal setting

III. CABLE QUALIFICATION AND SQUIB BATCH TESTING

Before the flight squibs were delivered by SDI, two test units were modified by removing their pressure taps; and cable assemblies were fabricated. These units were then subjected to the temperature shock and vibration tests described in Appendix B before being fired in the squib test chambers at ambient temperature and pressure. Squibs 401 and 429 of the flight group were put through the same test sequence to establish further cable-qualifying data and to check the performance of the flight squibs against the qualification test data presented in Appendix B. Table D-3 summarizes the environmental test and firing data of these tests. All tests were successful and the data showed good correlation with that of previous tests.



Sketch D-1

The four squibs were fired in JPL Bldg. 117 using the test chambers described in Appendix B. A rheostat was constructed to bring the firing current down to 9 amps. Sketch D-1 shows the firing-circuit diagram.

Table D-3. Squib-cable assembly test data

Serial number	Resistance data, ohms				Firing data, time in milliseconds					
	Initial resistance	Temp. shock	Axial vibration	Lateral vibration	Firing number	Peak pressure psi	Bridge delay (t_1)	Closure delay (t_2)	Pressure rise delay (t_3)	Total delay (t)
331	0.59	0.60	0.60	0.60	37	310	9.7	1.3	1.3	12.3
332	0.55	0.58	0.59	0.59	38	300	10.5	1.0	1.9	13.4
401	0.62	0.61	0.61	0.61	39	330	10.2	1.6	1.4	13.2
429	0.59	0.58	0.58	0.57	40	330	10.6	1.2	1.4	13.2

REFERENCES

1. Culling, H. P., "Statistical Methods Appropriate for Evaluation of Fuse Explosive-Train Safety and Reliability," NAVORD Report 2101, United States Naval Ordnance Laboratory, White Oak, Maryland, October 13, 1953.

2. Bombara, E. L., "Reliability of Compliance With One-Sided Specification Limits When Data is Normally Distributed," ARGMA TR 2BIR, Army Rocket and Guided Missile Agency, Redstone Arsenal, Alabama, September 15, 1961.